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QUALITY AND PROCESSING OF A WAXY SPRING WHEAT PROTOTYPE

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"QUALITY AND PROCESSING OF A WAXY SPRING WHEAT PROTOTYPE"

FINAL REPORT
(April 1, 1998 – August 31, 2001)

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EXECUTIVE SUMMARY

ASTRACT

Waxy starch was isolated from a waxy wheat prototype. The composition and structure of waxy wheat starch were determined and compared with its counterpart in corn. Waxy wheat flour had slightly weaker dough properties while waxy wheat starch had unique pasting properties. Flour blending with waxy wheat and CWRS, CWES and CWAD wheat significantly affected the quality of its end –products from noodle, pasta and cookie processing. The development of experimental spring wheat lines combining strong gluten properties with the waxy wheat trait would appear to hold promise based on the results from this study.

SUMMARY

A waxy wheat prototype was developed through collaborative research between the CDC and PBI-NRCC. The waxy wheat prototype contained lower levels of starch and less than 3.6% amylose. Waxy wheat flour produced an intermediate strength dough although the stability of the dough was slightly less than that of a soft wheat flour. The weaker dough properties of the waxy wheat flour were compensated for in a flour blend with strong gluten wheat flour to produce a suitable texture for noodle products. Waxy wheat starch had unique properties exhibiting higher viscosity, gelatinization temperature, degree of crystallinity, and significant resistance to retrogradation. Higher swelling power and lower solubility of waxy wheat starch resulted in lower cooking loss of noodle products from flour blends. Blending waxy wheat flour and starch with strong gluten wheat led to a more stable texture profile of end products indicating potential for frozen or partially cooked ready- to-eat products. Pasta and macaroni products from semolina blends with waxy wheat flour and starch were rated as acceptable in sensory evaluations. Most of the cookies prepared from waxy wheat flour blends were also deemed acceptable and scored higher than control cookies.

TECHNICAL REPORT

ABSTRACT

Waxy wheat flour had higher peak viscosity and swelling power compared with non-waxy wheat. Waxy wheat starch had higher viscosity, more closely-packed crystal structure, greater retrogradation resistance and higher rates of α-amylolysis than non-waxy starch. Flour

blending with waxy wheat and CWES and CWRS wheats improved the texture of the end product in noodle processing. Blending with waxy wheat starch compared to waxy wheat flour was more effective in maintaining dough color. The dough color changed rapidly within 4 hr storage after dough was made and this discoloration was highly correlated with protein and polyphenol oxidase (PPO) content in flour. Replacing semolina with waxy wheat markedly reduced hardness, chewiness and cooking time of pasta. Macaroni products from semolina blends with waxy wheat flour and starch were rated the same as products from semolina alone. Waxy wheat starch was the favorable blending ingredient in cookie flour even though cookie had a pale yellow color at high level of blending.

BACKGROUND AND OBJECTIVES

It is well documented that waxy starches differ from non-waxy starches in their characteristics and utilization. These waxy materials (flour and starch) have been found to have advantages for certain food and industrial uses. For instance, wheat with a higher content of amylopectin is preferred for the production of Japanese *udon* noodles (Miura and Tanii 1994, Seib 2000). A variety of waxy-type starches are now available from diverse cereal crops (waxy crops) such as corn, sorghum, barley, rice, etc. On the other hand, some trials have been made to develop new cultivars of waxy wheat since there were no commercial waxy wheat varieties available (Hayakawa et al. 1997). Yasui et al. (1996) developed three waxy wheat lines that contained apparent amylose of 1.2-2.0 g/100g as compared to 26.0-28.4 g/ 100 g in their non-waxy parents. The peak temperature and gelatinization enthalphy for waxy wheat starch were significantly higher than those of non-waxy starch (Hayakawa et al. 1997 and Yasui et al. 1996). The waxy wheat starch was also characterized by having greater retrogradation resistance. The availability of this waxy material will open a new avenue for wheat utilization and diversification.

A collaborative research program between the CDC and PBI -NRCC on the development of waxy wheat in Canada has led to the development of waxy wheat prototypes that needed to be evaluated for their characteristics and potential food processing. The same research team (Demeke et al. 1997, 2000) has evaluated Canadian and other wheats for waxy proteins, the enzymes involved in the synthesis of amylose. They identified some wheat accessions with mutations at the Wx loci that have been used to develop partially and fully waxy Canadian spring wheat.

The objective of this project was (1) to determine waxy wheat starch composition and structure in comparison with its corn counterpart, (2) to investigate the physicochemical properties of waxy wheat flour and starch, (3) to investigate the technological potential of waxy wheat in noodle and macaroni products, (4) to evaluate blends of waxy and soft wheat in cookie and (5) to correlate waxy wheat starch characteristics with its end-use quality.

EXPERIMENTAL METHODS

Wheat Samples

A waxy wheat experimental line was developed during a previous CDC/PBI ADF Project. The waxy wheat prototype, lacking all of the three Wx proteins, was grown at Saskatoon, SK in 1997 (F6 seeds). The CWRS wheat, cultivar Neepawa, was grown in plots adjacent to the waxy wheat. This cultivar was used as a wheat check for comparison purposes. The CWRS wheat cultivar, Katepwa, CWES wheat cultivar, Glenlea, and soft wheat cultivar, AC Reed, were also included for comparison purposes in the product processing.

Physicochemical Properties of Wheat Flour

The wheat grains were milled into flours on a Brabender Quadrumat Jr Flour Mill following tempering at 14.5, 15.0 and 14.0 % for waxy, Neepawa and AC Reed, respectively, over an 18 hr period. The flour and bran yields are reported in Table 1. There were no marked differences in flour yield between normal and waxy wheat grains. Flours were also prepared from Katepwa and Glenlea for noodle processing and the percent of recovery and flour yield are reported in Table 2. Waxy wheat meal was prepared using a Udy grinder.

Mixograph characteristics of HRS (Neepawa), SWS (AC Reed) and waxy wheat flours were measured on a mixograph interfaced with an IBM computer operated by Mixsmart software. Farinograph and Visco/amylograph characteristics were measured on normal and waxy wheat flours.

Waxy and normal wheat grains were analyzed for their contents of starch and amylose. Starch was measured as glucose according to the method described by McCleary et al. (1997). Swelling power was determined and calculated as described by Sasaki and Matsuki (1998).

Starch Isolation

Starches were isolated from waxy and normal wheat grains by wet milling (Abdel-Aal et al. 1997). The grains were steeped in 0.5% sodium bisulfite solution for 16 hr. The softened grains were drained and rinsed with distilled water, then homogenized in a Waring blender for 2 min. the homogenate was passed through a 210 μm polypropylene screen. The residue was homogenized two more times and the combined extracts passed through a 70 μm polypropylene screen. The filtrate was allowed to sediment at 4°C and the supernatant was discarded. Starch was then purified by suspension in 0.05N NaOH solution for 1 hr with continuous agitation, then centrifuged to remove the soluble proteins and to scrap off the light brownish proteinaceous layer. The starch was resuspended in distilled water and neutralized to pH 7.0 with 0.5N HCl and centrifuged. The starch was washed thoroughly on a Buchner funnel with distilled water,

following by 95% ethanol. The filter cake was dried overnight at 35-40°C. Native waxy and normal corn starches from Sigma Chemical Co. (St. Louis, MO) were included for comparison.

Characteristics of Waxy Wheat Starch

The granule shape and size of wheat and control starches were examined by scanning Electron Microscope and Image Analyser. Waxy wheat starch crystallinity was determined by X-ray diffractometry. Pasting properties, DSC characteristics, and digestibility of waxy and non-waxy wheat starch were investigated.

Noodle Processing

i) Preparation of Flour Dough and Noodle

Wheat flour was mixed with a salt solution (1.5% sodium chloride, 35% absorption) for white salted noodle or an alkaline solution (0.3% K_2CO_3 + 2.7% Na_2CO_3) for chinese yellow noodle at high speed for 5 sec and crumbly dough was passed through the roller (No. 1), folded and passed through again. Then, dough was rested for 1hr and a dough sheet was made by passing through each of sheeting roller, No.1 (twice),2, 4 and 6. For convenience of color determination, the dough sheet was cut into a round shape (3.3 cm dia., 1 mm thickness). Noodles were prepared by passing through the sheeting rollers followed by a cutting roller.

ii) Color Determination of Dough Sheet

Dough sheets were cooked in boiling water for 6 min, rinsed with cold water and the excess water removed by wiping prior to color determination using a Hunterlab MiniScan, XE, standardized with a white color standard . Color of fresh or cooked dough sheet was measured after storage for 0, 2, 4, 24, 48 and 72 h at RT or 4°C.

iii) Texture Determination of Dough Sheet and Noodle

For texture measurement, the dough sheet was cut into a round shape (3.3 cm dia., 1 mm thickness) or noodle, and cooked in boiling water for 6 min, rinsed with cold water, and wiped free of water on the surface before placing on a flat metal plate. Four replicates of cooked dough sheet were prepared and evaluated by Texture Profile Analysis (TPA) using the TMS-90 Texture Test System equipped with TPA-1 cell (Food Technology Corporation, MD) within 5 min after cooking.

Noodle (20g) were cooked in 500 ml of boiling distilled water for 6 min and rinsed with cold water. Cooking water was collected for determination of cooking loss. Cooking water (50 ml) was placed in a 100 ml beaker and dried to constant weight at 90°C. Cooking loss of noodle was calculated as follows:

Cooking loss (%) = [dried cooking water (g)/ uncooked noodle weight (g)] x 100

Cooked dough sheet or five strands of cooked noodle were placed on a flat metal plate and compressed twice to 70% of noodle height using a TPA-1 cell with 300 lb of force transducer. From the TPA curve, hardness (height of peak), cohesiveness (the ratio between the area under the second peak and the area under the first peak), adhesiveness (negative area between the first and the second peak), springiness (distance of the second area), gumminess (the product of hardness and cohesiveness) and chewiness (the product of gumminess and springiness) were determined.

iv) Eating Quality of Noodle Products

Noodle (white salted) was made from Katepwa, Glenlea, AC Reed flours and flour blends with waxy wheat flour or starch by the procedure described earlier. Noodles were dried at room temperature overnight and kept in a plastic bag for further tests. Dried noodle was cooked for 6 min in boiling water and rinsed with cold water four times and kept in cold water prior to evaluation. Panelists were asked their preference of noodles for brightness, yellowness, surface smoothness, softness and elasticity on a scale of 9 points (1=dislike extremely, 9=like extremely).

Pasta Processing

i) Pasta Processing

Pasta product was prepared from semolina and semolina mixed with waxy wheat flour (WF, 0 to 40%) or starch (WS, 0 to 30%) on a small-scale PastaMatic (SINAC Appliance Co., New York, NY) following dough preparation in a separate mixer. Water absorption used was 38% and some adjustment was made for semolina mixed with WF or WS. The uniform dough was shaped using a Taglitella media disc to facilitate quality evaluation including determining texture profile. Pasta was dried at room temperature overnight and kept in a plastic bag for further quality evaluation.

Color of pasta was measured using a Hunterlab MiniScan, XE, standardized with a white color standard. Four replicates of cooked pasta were evaluated by Texture Profile Analysis using the TMS-90 Texture Test System (Food Technology Corp.). Cooking loss of cooked pasta was determined.

ii) Eating Quality of Pasta and Macaroni Products

Dried pasta or macaroni product was cooked for 20 min (or more) in boiling water until it was fully cooked. Panelists recorded their preference of pasta and macaroni products for firmness, stickiness, color, appearance and flavor on a scale of 4 points (1=very poor, 4=good).

Cookie Processing

Baking quality of cookie was based on the AACC procedure Method 10-52. Cookie texture was measured using the TMS2000 Texture Test System. For sensory evaluation, cookies were prepared using modified methods based on AACC 10-52 to diminish the confounding effect of sweetness during the evaluation. Cookie size and baking time were reduced.

RESULTS

A1. Wheat Grain and flour

Waxy wheat grains had a lower level of starch than normal wheat (approximately 4 units). Also, waxy wheat contained a very low concentration of amylose, 3.6% (dry basis) versus 26.9% in Neepawa (wild type) wheat grains. This waxy wheat prototype is 96% Wx and 4% wild type (i.e. not pure) based on the McCleary et al. Method. Using different methodology, Demeke et al. (1999) could not detect amylose for the same wheat line.

A2. Physicochemical Properties of Waxy Wheat Flour

The mixograph characteristics of the doughs were based on 10.0 g of flour (14% moisture basis) and water absorption of 65%. Compared to Neepawa and AC Reed wheat flours, waxy wheat flour formed an intermediate strength dough as indicated by peak value (percentage of the full scale, torque%) (Table 3). The development time of waxy flour, however, was lower than both other flours, indicating rapid dough development. The mixograph curve slope of waxy wheat dough was also lower than that of HRS and SWS flour, showing moderate tolerance and sensitivity to mixing time. But, the mixograph curve band width and integrated area of waxy dough were intermediate between HRS and SWS wheat flours demonstrating that waxy wheat flour produce doughs that have an intermediate strength and require moderate work to develop.

Farinograph characteristics of normal and waxy wheat flours are presented in Table 3. Flour water absorption of waxy flour was higher than that of HRS and SWS wheat flours. The shape of farinograph curves of waxy wheat flour indicate that waxy flours produced weaker doughs compared to HRS wheat flours. A rapid build-up in dough consistency of waxy wheat to a sharply defined peak occurred followed by a relatively rapid breakdown. The stability of waxy wheat doughs to mixing was slightly lower than that of SWS wheat flour, but much less than

that of HRS wheat. Mixing tolerance index of waxy and soft wheat flours were higher than hard wheat flour indicating weaker doughs.

The visco/amylograph characteristics of normal and waxy wheat flours were measured on 12% slurries with and without mercuric acetate as an enzyme inhibitor using a Brabender visco/amylograph (Table 3). The pasting and peak temperatures of waxy flour were lower than those of HRS and SWS wheats. Both temperatures were not influenced by the presence of the enzyme inhibitor, except for peak temperature of waxy wheat which decreased due to the addition of mercuric acetate. On the other hand, peak viscosity was markedly affected for the three wheat grains. Waxy wheat flour exhibited the highest viscosity followed by SWS wheat and HRS wheat. The effect of enzyme inhibitor on viscosity of waxy flour was greater than those of normal wheat flours.

The sedimentation test is a good predictor for estimating the gluten strength of wheat. Waxy wheat had an intermediate gluten strength based on the sedimentation test. The sedimentation volume of waxy flour was between that of HRS and SWS wheat flours. Falling number is a measure of viscosity of flour slurries in sec, with high values being predictive of low α-amylase activity. HRS wheat flour, which had a higher falling number value also had less α-amylase activity. The falling number test was not applicable to waxy wheat due to the absence of amylose which generates the viscosity of the starch slurry under the test conditions (boiling for 1 min).

Generally speaking, waxy wheat flour with high viscosity and intermediate dough strength could have potential in noodle production or in blending with SWS wheat flour to produce a variety of frozen pastry products.

A3. Swelling and Solubility Properties of Waxy Wheat Flour and Starch

Swelling power is a simple test and was recently recognized as an indicator of noodle quality (Sasaki and Matsuki 1998). The swelling power of normal and waxy wholemeal is presented in Fig. 1. The swelling power of waxy wheat increased sharply as the temperature was increased, reaching its maximum at 90°C, while swelling power of normal wheat increased slightly up to 80°C. Accordingly, there were significant differences between waxy and normal wheat in their swelling power at higher temperatures (85-90 °C). Based on the results obtained, swelling power of wholemeal at 90 °C would be recommended for identifying partial or fully waxy wheat in breeding programs aimed to develop these classes of wheat. The same finding was observed for starches isolated from normal and waxy wheats (Fig. 2). Waxy wheat starch exhibited much higher swelling than its corn counterpart.

The solubility of waxy and non-waxy wheat starches was similar when heated up to 85 °C, after that there were differences in their solubilities (Fig. 3). Non-waxy wheat starch had a higher solubility as compared to waxy starch due to solubilization and leaching of amylose in

normal or non-waxy wheat. This property could be used to identify waxy materials in screening programs in addition to the swelling power mentioned above.

A4. Waxy Wheat Starch

A4.1. Starch Isolation and Extraction Efficiency

Yield and extraction efficiency of starches isolated from waxy and normal wheat cultivars are reported in Table 4. Waxy wheat yielded slightly less starch, over-all, as compared to normal wheat, but its starch extraction efficiency was slightly higher. Isolation of starch from whole wheat grains resulted in lower starch damage compared to starch damage content in wheat wholemeals (Table 5). Waxy materials (wholemeal and starch) had a slightly higher level of starch damage compared to normal wheat wholemeal and starch. Generally, isolated wheat starches had lower starch damage levels than control corn starches.

A4.2. Granule Size and Composition

Waxy and normal wheat starches contained two types of starch granules: type A-granule (larger granule, >10 μm) and type B-granule (small granule, 1-10μm) (Figs. 4 and 5). They also showed similar average granule diameter and percent of type A and type B starch granule (Table 6). On the other hand, waxy and normal corn starches had one size-population of granules. Based on the average granule diameter, corn starch granules had a larger diameter than those of wheat starch.

The chemical composition of waxy and normal wheat and corn starches is presented in Table 7. Starch content was similar in wheat and control corn starches, averaging 93%. Amylose contents in waxy wheat and corn starches were much lower than those of normal wheat and corn starches, i.e. 2.9-3.2% versus 21.0-26.9%. Protein, hexane-extractable fat and ash contents were similar in waxy and normal wheat starches as well as in waxy and normal corn starches, except for ash content of normal wheat starch which was higher than that of waxy wheat starch. Wheat starches possessed a higher level of fat than corn starches.

A4.3. Waxy Starch Structure

Since X-ray diffractometry measures the starch granule crystallinity, a crystalline or amorphous region of starch granules could be estimated by measuring the areas under principal peaks. The amorphous region can be represented by the area between a flat horizontal baseline and a tail-to-tail baseline of each peak, while the crystalline region can be estimated by the sum of the surrounding total area between each peak and a tail-to-tail baseline. The amorphous and crystalline region of a waxy wheat starch sample and their areas are illustrated in Fig. 6. The area under the peak of crystalline and amorphous regions was measured using a compensating polar

planimeter. These areas were used to calculate crystallinity % according to Fujita et al. (1998) as follows:

Crystallinity (%) = Ic / (Ia + Ic) x 100

where: Ic = crystalline area on the X-ray diffractogram and Ia = amorphous area on the X-ray diffractogram.

The percent of relative crystallinity for the major peaks was calculated using the following equation:

Percent relative crystallinity = starch peak area / standard (alumina) peak area x 100

Reagent grade alumina powder was used in X-ray analysis as an internal reference standard (reference peak at 2θ 38.50°) for measuring the relative crystallinity of starch diffraction peaks providing an absolute diffraction angle (2θ). Because there was an area between the flat horizontal baseline and the tail-to tail baseline of alumina peak, starch crystallinity was corrected using the actual estimated alumina crystallinity as follows:

Corrected crystallinity (%) = uncorrected crystallinity % / estimated alumina crystallinity x 100

The X-ray diffraction A-type pattern was observed for both waxy and normal wheat starch (Fig. 7), showing major peaks near d-spacings of 5.8, 5.2, 4.9 and 3.8 Å. However, significant differences in the degree of crystallinity were observed between waxy and normal wheat starch (Table 8). Waxy wheat starch crystallinity was estimated to be 21.2% compared to 15.7% for normal wheat starch. There were also differences between waxy and normal starch in percent relative crystallinity of the major peaks in the diffractograms. Waxy wheat starch exhibited X-ray diffraction with higher percent of relative crystallinity. The higher crystallinity of waxy wheat starch reflects a higher percentage of amylopectin. In other words, waxy starch has a more closely-packed crystal structure due to the presence of amylopectin. Other investigators have reported that waxy starch has a higher crystallinity compared with non-waxy or normal starch (Hayakawa et al. 1997; Fujita et al. 1998).

A4.4. Waxy starch Digestibility

Native ungelatinized waxy and non-waxy wheat and corn starches were hydrolyzed by pancreatic α-amylase over a period of time (15-300 min). The relationship between incubation time and concentration of released maltose as an indicator of starch hydrolysis was plotted (Fig. 8). As expected, the degree of starch digestibility increased as the incubation time was increased, but at different rates for each starch. The in *vitro* starch digestibility rate (mg released maltose/g starch/hr) was calculated (Table 9). Despite the high crystallinity, waxy starches exhibited higher rates of digestibility than non-waxy starches. This observation was made in both wheat and corn

starches. The higher rate of starch digestibility in waxy starches could result form the more accessible positions for α-amylase in branched starch granule.

The present results demonstrate that waxy starches are similar to non-waxy and normal starches in granule shape and size but not in starch crystallinity. It has been reported that crystallinity is more important than granule size regarding gelatinization properties (Fujita et al. 1998). These results also suggest that there might be some structural differences between waxy and normal wheat starch. Also, there were differences in starch digestibility rate between the two types.

A4..5. Pasting Properties of Waxy Wheat Starch

Texture of end-use wheat products was found to be mainly influenced by starch, the major component in wheat grains. Pasting characteristics of waxy and non-waxy corn and wheat starches during cycles of heating and cooling were studied (Table 10 and Fig. 9). Peak viscosity of waxy wheat starch was much higher than normal wheat and corn starches due to the high swelling power of waxy starches. The set-back viscosities of waxy starches were lower than those of non-waxy starches indicating good resistance to retrogradation. The stability of normal and waxy corn wheat starch gels under cold or frozen storage was determined according to the method of Zheng and Sosulski (1998). There were also marked differences in net syneresis of waxy and normal starch gels, particularly under frozen storage (Table 11). Generally, waxy starch gels were more stable than normal starch gel when stored at 4°C or -15 °C. The stability of waxy wheat starch gels was similar to waxy corn starch gels either under cold or frozen storage for the test period (7 days).

A4.6. DSC Characteristics of Waxy Wheat Starch

The DSC characteristics of normal and waxy corn and wheat starches are reported in Table 12. The transition temperatures, e.g. onset temperature (T_o), peak temperature (T_p) and conclusion temperature (T_c) of waxy starches were higher than those of non-waxy in both corn and wheat particularly for T_p. The enthalpy of gelatinization (ΔH) of waxy starches was also higher than non-waxy starches particularly for corn. Similarly, Hayakawa et al. (1997) and Yasui et al. (1996) found that peak temperature and gelatinization enthalpy of waxy wheat starch were significantly higher than those of non-waxy starch.

The current results show that waxy starches have unique properties over their counterpart non-waxy starches in terms of higher viscosity and greater retrogradation resistance. Also, waxy starches were found to have higher swelling power and lower solubility on heating at high temperatures (85-95 °C). These characteristics are preferred for certain wheat products such as wheat noodles and frozen products.

A5. Utilization of Waxy Wheat Flour and Starch

The wheat grains were milled into flour on a Brabender Quadrumat Jr Flour Mill following tempering at 14.5%, 15.0% and 14.0% for waxy, Katepwa, Glenlea, and AC Reed over a 18 hr period. The percent of recovery was 94.5-97.3%. Glenlea (CWES) which has a strong gluten strength was included to compare the end products with that from other wheats and flour blends with waxy wheat flour or starch. Waxy wheat starch was isolated by wet milling as described earlier.

Chemical compositions of flour from normal and waxy wheat are reported in Table 13. The protein was higher in CWRS wheat, Katepwa while starch was higher in AC Reed and CWES wheat, Glenlea. There were no marked differences except protein and starch contents in chemical composition of normal and waxy wheat flours. Physicochemical characteristics of flours are shown in Table 14. In mixograph, Glenlea (CWES) showed a typical pattern for strong wheat flour such as a broad band width and long mixing time (4.9 min) to reach the peak while waxy wheat flour reached the peak in a shorter mixing time (1.6 min). Wet gluten and sedimentation volume were related to protein content of flour and values for waxy wheat flour were between CWRS and soft wheat flour. There was no significant difference in swelling power among flour samples.

A5.1 Noodle Processing

A5.1.1. Color Determination of Dough Sheet

Colors of flour and dough from waxy wheat and common wheat are presented in Table 15. SWS wheat (AC Reed) compared to waxy wheat and Katepwa had a high L-value and low yellow score indicating whiter noodle end product. Color readings of flour and fresh dough from waxy wheat and common wheat, Katepwa were similar. Dough formation with salt solution reduced L-value and increased yellow score in color readings due to oxidation of phenolic compounds in flour during mixing. The correlation between polyphenol oxidase (PPO) and L-value was investigated since PPO is capable of oxidizing various phenolic compounds and has been suggested as the cause of darkening of noodles. High correlation coefficients were obtained between PPO and L-values; 0.936 for flour, 0.997 for fresh dough and 0.989 for cooked dough, respectively.

Waxy wheat flour (WF) or starch (WS) was mixed with HRS wheat (Katepwa) and SWS wheat (AC Reed) flour to investigate their influence on dough color (Table 16). Fresh and cooked dough sheets of mixed flour were stored at RT (room temperature) or 4°C for up to 72 hr and the color of dough sheets were measured after 2, 4, 24 and 72 hr of storage, respectively. L-values of fresh dough sheets from mixed Katepwa flour declined sharply after 24 hr of storage at

RT (Fig.10). The addition of waxy wheat flour (WF) or starch (WS) in Katepwa and AC Reed flour increased L-value of their dough sheets. Mixed flour with WS made a whiter dough sheet than those with WF. The storage at a low temperature (4°C) delayed deterioration of dough colors. Cooked dough sheets had an almost steady L-value during a storage at both room and low temperature (Fig. 11). L-values of dough were improved by cooking in boiling water.

Colors of dough from Glenlea, and flour blends with waxy wheat flour or starch are presented in Table 17. L-values (or brightness) of flour blends with waxy wheat flour were similar among samples. The addition of waxy wheat starch compared to waxy wheat flour was more effective in maintaining dough color (lightness). L-values of fresh dough sheets declined slightly during storage at RT and 4°C while values of cooked dough sheets were steady and similar among samples at RT (Fig.12). There was a significant difference in L-values of cooked dough sheets among samples during 72 hr storage at 4°C. Dough from Katepwa had the highest L-value among samples (Katepwa>Glenlea>waxy wheat) during storage at 4°C.

When flour from Katepwa and Glenlea was mixed with WF or WS, the deterioration of dough color was very similar among blends and it was not affected by the storage temperature (Fig. 13). Lightness of cooked dough changed (increased) within 4hr of storage (Fig. 14).

Alkaline dough had higher yellowness score which is desirable for chinese noodle than white salted dough. Flour mixed with waxy wheat flour increased yellowness of dough while flour with waxy wheat starch reduced yellowness (Table 18). Deterioration of color of alkaline dough was similar to that of white salted dough during storage at RT or 4°C for up to 72 hr (Fig.15). Cooked alkaline dough had higher L-values than fresh alkaline dough and L-value of cooked alkaline dough was slightly increased by storage time (Fig. 16). Overall, color of dough changed rapidly within 4 hr storage after dough was made with salt or alkaline solution. Discoloration of dough is highly correlated with protein and polyphenol oxidase (PPO) and the same observation was obtained in our experiment. Katepwa and waxy wheat had higher protein and PPO content than AC Reed.

A5.1.2. Texture Determination of Dough Sheet and Noodle

Texture profile of AC Reed (soft wheat) was used as a standard for comparison purposes. Dough from waxy wheat flour alone was very sticky, fragile and had low hardness values, gumminess and chewiness (Table 19). The texture profile of dough from Katepwa was similar to that of commercial flour, which exhibited a slightly over-strong texture for noodle. AC Reed had a good appearance as indicated by the bright color of the dough for white salted noodle, but had a poor appearance for chinese noodle which requires a yellower color. Glenlea (extra strong wheat) had higher values among samples for hardness, gumminess and chewiness in texture profile (Table 20). On the other hand, overall texture of Katepwa and Glenlea noodle was softened by replacing a portion of flour with waxy wheat flour (WF) or starch (WS)(5 or 10%). Addition of waxy wheat starch (WS) reduced texture dramatically in both samples, especially Glenlea. Flour blends of Glenlea with waxy wheat flour or starch exhibited a noodle texture profile very similar to that of unblended AC Reed (soft wheat) flour, which is considered good

material for noodle- making. However, flour blends of Katepwa (1999 crop) and WF or WS had lower texture profile values compared to AC Reed flour. This might indicate that the strong gluten structure of Glenlea is holding the dough structure while addition of WF and WS tends to loosen the dough structure, resulting softer texture in the noodles resulting after cooking. The details of structural changes need to be investigated in a further experiment to explain these textural changes.

Cooking loss (%) was higher in fresh noodle from Glenlea flour blends with WF or WS than in Katepwa flour blend. Cooking loss was positively correlated to the starch content of the flour sample. AC Reed containing more starch had the highest cooking loss value while waxy wheat, containing the least starch, had the lowest value. Addition of WF and WS reduced cooking loss in both flour blends.

Texture profiles of dried noodles prepared from waxy wheat, Katepwa, AC Reed and flour blends with WF or WS are presented in Table 21. Cooking loss (%) was higher in noodle from waxy wheat while it was low in noodle from Katepwa. Addition of WF reduced cooking loss while WS increased cooking loss. Hardness and adhesiveness of noodles were increased by blending flour with waxy wheat flour or starch. Water used in dough formation may contribute to these textural changes. During dough formation, water is distributed to flour components, such as starch. Redistribution and rearrangement of water during the drying process might enhance the binding force among starch molecules resulting in a harder texture of noodles. Since water in fresh noodle was not subjected to the redistribution and rearrangement during the drying process, there wasn't any enhancement of binding force among starch molecules resulting in a softer texture in fresh noodle than dried noodle.

The major changes in texture during storage at 4°C for up to 24 hr are shown in Figure 17. Hardness and chewiness of noodles were sharply increased within 4 hr storage and stayed almost steady up to 24 hr. There were only slight changes in texture profile of noodles during storage from 24 hr up to 72 hr. Texture of noodle from flour blends with waxy wheat flour was more stable than that from the others.

Noodles from Glenlea alone and flour blends with WF or WS had higher hardness and chewiness values but lower values in cohesiveness than noodles from Katepwa and flour blends (Figure 18). Overall, texture profile of Glenlea and flour blend with WF or WS was more stable during storage at 4°C than that from Katepwa. Blending WF and WS with Glenlea (extra strong wheat) instead of Katepwa (mellow wheat) led to more stable texture profiles of end products during storage at low temperature. This could be an indication that waxy wheat flour or starch can be used in the manufacturing of instant ready- to- eat noodle by blending flour with a strong gluten wheat variety.

Hardness of dough from waxy wheat was greatly increased when dough was made with alkaline solution for chinese noodle. Alkaline dough had a lower texture profile than dough made with a salt solution. Adhesiveness, gumminess and chewiness were sharply reduced in alkaline

dough. Waxy wheat flour and starch in alkaline dough played the same role as in white salted dough. Texture of alkaline dough was diminished by addition of WF or WS. Alkaline solution can cause denaturation of protein in flour resulting in a hardening of the texture, and can cause partial gelatinization of starch in flour, resulting in a softer texture at the same time. The ratio between denaturation of protein and gelatinization of starch play a major role in governing the texture profile of alkaline dough. AC Reed which contained less protein but more starch, had greater changes in texture profile than Katepwa or waxy wheat.

A5.1.3. Eating Quality of Noodle Products

All noodle products in this experiment were rated as acceptable products having an overall average score of 6.5. Noodles having a whiter color (brightness) were rated higher than those having a yellowish color (Table 22). AC Reed was the most preferred flour for noodle in terms of color due to its brightness, and the preference of noodle from Katepwa and Glenlea flours was increased when their flour was blended with waxy wheat flour (WF) or starch (WS) resulting in increased brightness. Blending flour with WF or WS improved color but reduced firmness (low score in softness) and chewiness (low score in elasticity) of noodle products. From the overall results, increased brightness and a certain level of softness and chewiness in mouth-feel were desirable factors for white salted noodle products.

A5.2. Pasta Processing

Replacing semolina with waxy wheat flour had no significant effect on the color of the pasta end- product. On the other hand, waxy wheat starch enhanced whiteness and diminished yellowness in the pasta product (Table 23). In terms of color of product, waxy wheat flour rather than starch can be used to replace semolina since yellowness in pasta products is preferred.

Hardness and chewiness of cooked pasta was markedly reduced when semolina was mixed with waxy wheat flour or starch. Waxy flour, over 30%, in the semolina sharply changed the texture profile of cooked pasta. Addition of waxy wheat starch had a larger effect on texture profile than waxy wheat flour. Cooking time of pasta was reduced by mixing semolina with waxy wheat flour or starch.

Pasta from a semolina blend with WF or WS compared to semolina alone had lower ratings in firmness, color and appearance (Table 24). Blending semolina with WF or WS reduced the firmness of the pasta and increased the surface stickiness, which is related to the lower rating in appearance of end products. Results indicate that the difference in stickiness among samples was not detected in mouth-feel even though products having soft and sticky looks were rated as low in appearance. Overall, pasta products from semolina blend with WF or WS were rated as inferior, having an average of 2.7 compared with 3.4 for pasta from semolina alone.

On the other hand, blending semolina with WF or WS did not reduce the scores for the resulting macaroni products. Macaroni products from semolina blend with WF or WS had the same preference (average rating of 2.8) as that for products from semolina alone (Table 25). It appears that yellowness of macaroni did not affect the scores of the product while increased yellowness was more desirable in pasta products. Also, the difference in firmness among samples (mouth-feel) was sensed easily in pasta products but was not distinguished in macaroni products.

A5.3. Cookie Processing

A5.3.1. Cookie Product

Waxy wheat meal, flour and starch were blended with flours from AC Reed (SWS), CDC Bavaria (soft spelt), Katepwa (CWRS) and Glenlea (CWES) to determine the effect on cookie products. The percent of blending was 5, 20, 30, 40, 50 and 80 for waxy wheat meal and flour. Waxy wheat starch at rates of 1, 3, 5, and 10% was blended in flours to determine its effect on cookie spread. Protein and starch content of waxy wheat resulted in increasing protein content and decreasing starch content in flour blends with waxy wheat meal and flour (Table 26 and 27). Total dietary fiber was increased in flour blends with waxy wheat meal and flour, decreased in blends with waxy wheat starch.

There was no significant difference in the spreading factor of cookies from flour blends until the percent of blending reached 40%. Blending over 50% with waxy wheat meal and flour slightly reduced the spread factor for all flour samples. This reduction in spread was small in cookies from flour blends with waxy wheat starch. Most of the cookies from flour blends were brown in surface color, with an even pattern in top grain, and yellow interior color. Cookies from AC Reed and CDC Bavaria, had a slightly higher spread, but the surface and interior color of the cookies was similar with those from hard wheat (Table 28 and 29). Cookies from soft wheats were more open in interior structure than those from hard wheat.

Blending with waxy wheat meal in excess of 50% resulted in a dark surface color and dense interior structure of the cookie. Blending with waxy wheat meal also increased the hardness of the cookie product. On the other hand, most of the cookies from flour blends with waxy wheat flour had a lighter surface color, but a similar interior color to cookies made from soft wheat. With blends exceeding 40%, waxy wheat flour led to an interior structure that was dense and coarse- grained.

Cookies from CDC Bavaria flour blends with waxy wheat meal, flour and starch had a similar baking quality to those from AC Reed flour blends. Cookies from hard wheat flour

blended with waxy wheat meal, flour and starch had a comparable baking quality to that from the commercial control flour.

There was no significant difference in interior structure of cookies from flour blends with waxy wheat starch. Waxy wheat starch at 1 to 5% had no effect on surface and interior color of cookie products while cookies with 10% waxy wheat starch content had a bright and pale yellow color.

Waxy wheat meal resulted in a reduction in L and b values in cookies from flour blends. However, there was no marked difference in HunterLab color value of cookies with waxy wheat flour and starch. Cookies from soft wheat blends had similar L and b values with cookies from hard wheat blends. Cookies produced from a commercial flour without blending as a control were high in L value and low in b value.

A5.3.2. Quality Evaluation of Cookie Products

Waxy wheat meal in flour blends led to cookies having darker surface and interior colors. There was no significant difference in the surface and interior color of cookies from flour blends with waxy wheat flour and starch. Cookies produced from AC Reed and CDC Bavaria flour blends had similar spreads and were wider than control cookies prepared from the commercial flour (Table 30 and 31). Blending with waxy wheat meal reduced cookie spread. Cookies from the 80% blend had a similar spread to the control product. Cookie spread was also slightly reduced by increasing the waxy wheat flour in the blend.

Texture (hardness) was measured on baked cookies after a 24 hr rest period at room temperature (Fig. 19). CDC Bavaria cookies were slightly softer than AC Reed cookies. Blending with waxy wheat meal and flour increased cookie hardness, while waxy starch in flour blends decreased cookie hardness. Denser and coarser grains in the interior structure were observed in harder cookies.

Sugar snap cookies (AACC10-52) are typically sweet and contain high levels of sugar. Sugar snap cookies from all flour blends scored the same values in the sensory evaluation except in appearance and color (Fig. 20 and 21). It seems that a high level of sugar acted as a masking agent in cookies from all flour blends. For sensory evaluation, the baking formula was slightly modified to reduce sweetness and size of cookie for the convenience since the sweetness interfered with recognizing differences among cookies. Cookies were prepared based on AACC 10-52 with the reduction of sugar level from 69% to 50% (g/g flour) using a conventional oven.

On a 9-point hedonic scale, cookies prepared from flour blends with WF and WS were generally rated acceptable, having an overall score of 6.5 for AC Reed and 6.2 for CDC Bavaria compare with 5.6 for control cookies (Tables 32 and 33). No unique flavor characteristics were

identified in any cookies from flour blends. Cookies containing waxy wheat starch scored high in appearance and color. A high variance was found in sensory scores for cookies containing waxy wheat meal (from 8 to 3) due to the personal preference for high fiber content. Blending with waxy wheat meal significantly reduced cookie appearance, color and texture (mouth feel). Increasing the waxy wheat meal content in flour blends resulted in a harder cookie and a lower texture score. Blending with waxy wheat meal, especially over 40%, in CDC Bavaria and 80% in AC Reed, led to deteriorating cookie quality, resulting in lower sensory scores. Cookies containing waxy wheat starch scored higher overall, even though cookies with 10% waxy wheat starch had a slightly brighter and paler surface color. Hardness and spread of cookies were highly correlated with sensory evaluation scores. With the exception of cookies from flours containing over 40% waxy wheat meal, most of the cookies from flour blends scored higher than control cookies.

Cookies were defatted prior to chemical analysis to compare their chemical composition with the original corresponding flours. Protein and starch contents were lower in cookies compared with their corresponding flours, while ash content was increased (Table 34). Fat content was high, averaging 17%, due to the addition of shortening. Concentration of protein and starch in flours affected their concentration in the cookies resulting. Higher protein in CDC Bavaria compared to AC Reed flour, resulted in higher protein in its cookie product. Total dietary fiber was high in cookies containing waxy wheat meal which was expected.

CONCLUSIONS

Waxy wheat flour was found to have different functional characteristics when compared with either hard (HRS) or soft wheat flour(SWS, Spelt). Waxy flour formed an intermediate strength dough, requiring less time and energy for dough development. The flour exhibited higher peak viscosity and swelling power compared with non-waxy wheat. There were no differences in granule shape and size between waxy and non-waxy wheat starch. Waxy wheat starch exhibited higher gelatinization temperature and degree of crystallinity, indicating a more closely-packed crystal structure. Waxy starches demonstrated higher rates of α-amylolysis than non-waxy starches, and had unique properties in terms of higher viscosity and greater retrogradation resistance.

Waxy wheat flour and starch can be used in blending with strong wheat flours to improve the texture profile of its unblended product, which is too sticky and fragile to handle. Blending waxy wheat flour and starch with CWES wheat instead of CWRS wheat led to a more stable texture profile of the end product. This could be an indication that waxy wheat flour or starch can be used in the manufacture of instant ready-to-eat noodles by blending with strong gluten wheat flours.

Attempts to produce starch noodles with waxy wheat starch were not successful. Waxy wheat starch noodle was too sticky and fragile to maintain noodle shape. Starch noodles were completely dispersed into water or broken into pieces during the cooling step after cooking. Combination of waxy wheat starch (WS) with potato starch (PS) improved the shape of starch noodles after cooling but the product was still too sticky.

Pasta products from semolina blends with waxy wheat flour or starch were soft and had low gumminess and chewiness ratings after cooking. Pasta products prepared from semolina blends with waxy wheat flour or starch were rated as acceptable products but rated lower than pasta made from semolina alone. On the other hand, macaroni products from semolina blends with WF or WS were rated the same as products from semolina alone. Textural change in pasta produced from semolina blends was easily sensed while changes in macaroni products were not. It seems that the shape, including length and width of pasta products, partly contributed to the preference for end product mouth-feel.

Waxy wheat meal, flour and starch were blended with SWS and CWRS to measure the effect on their cookie quality. There was no significant difference in the spreading factor of cookies from flour with a 40% blend. The high ratio of blending in cookie flour slightly reduced the spread factor for all flour samples. This reduction in spread was small in cookies containing waxy wheat starch. Most of the cookies from flour blends were brown in surface color, even in pattern of the top grain, and yellow in interior color. Waxy wheat meal and flour can be mixed up to 40% with soft wheat flour for cookie processing. Cookies from flour blend with waxy wheat meal had a favorable crunch and toasty taste. Waxy wheat starch could be mixed up to 5% even though the resulting cookies had a pale yellow color. Cookies from flour blends with waxy wheat flour and starch were rated as acceptable products in sensory evaluations. Waxy wheat starch was the most favorable blending ingredient in cookie flours even though cookies had a pale yellow color at high level of blending. Most of the cookies from flour blends scored higher in sensory evaluation than control cookies with the exception of cookies containing waxy wheat meal.

IMPACT ON SASKATCHEWAN AGRICULTURE

This result will assist food processors in establishing a new food product based on this crop.

TECHNOLOGY TRANSFER

Abdel-Aal, E-S. M., Hucl, P., Chibbar, R.N., Han H.L. and Demeke T. 2000. Physicochemical and structural characteristics of flours and starches from waxy and non-waxy wheats. Poster Presentation at the AACC Annual Meeting, Kansas city, MO.

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ITEM "B". Deviations from original work plan – NIL

ITEM "C". Achievements – Physicochemical Properties of Waxy Wheat Flour and Starch, and Utilization of Flour Blends in Noodle, Pasta and Cookie Processing.

ITEM "D". Equipment – NIL

ITEM "E". Personnel

S. Zou (May 19, 1998 – May 31, 2001) – 50%

N.Y. Jai (July 1, 1999 – May 31, 2000) – 50%

E-S.M. Abdel-Aal (April, 1998 – June 30, 1999) – 20%

H.L. Han (July 1, 1999 – August 4, 2000) – 33%

(February 4, - June 30, 2001) – 30%

(July 1 - August 31, 2001) – 10%

P. Hucl (April 1, 1998 – August 31, 2001) – 2%

Table 1. Yield and recovery of Flour and Bran Fractions Milled from Normal and Waxy Wheat Grains

Starch source	Flour (%)	Bran (%)	Recovery (%)
Neepawa			
Range	69.7-70.2	29.8-30.3	97.2-97.5
Mean	70	30	97.3
SD	0.3	0.3	0.2
AC Reed			
Range	70.4-71.9	28.1-29.6	96.4-98.2
Mean	71.3	28.7	97
SD	0.8	0.8	1
Waxy wheat			
Range	68.4-69.4	30.6-31.6	96.9-97.8
Mean	69	31	97.2
SD	0.5	0.5	0.5

Table 2. Yield and recovery of flour and bran fraction of waxy, SWS, CWRS and CWES

	% Flour	% Bran	% Recovery
Waxy wheat	69.2	30.8	97.2
Common wheat			
AC Reed (soft wheat)	68.43	31.57	98.61
Katepwa (CWRS)	70.24	29.76	98.72
Glenlea (CWES)	71.25	28.75	98.50

Table 3. Physicochemical Properties of Normal and Waxy Wheat Flours

Property	Neepawa	AC Reed	Waxy wheat
	Mixograph		
Peak time (min)	2.3	1.8	1.4
Peak value (%)	61.7	50.4	59.9
Slope (%/min)	-1.9	-7.5	-10.2
Band width (%)	22.7	9.4	14.4
Area (%tq*min)	374.4	270.9	312.7
	Farinograph		
Flour absorption (%)	67	60	76
Arrival time (min)	1.8	0.5	1.1
Peak time (min)	3.2	1.1	1.6
Stability (min)	9.4	2	1.2
Mixing tolerance index (BU)	30	120	150
	Visco/Amylograph		
Pasting temperature (C)	72.0 (72.0)[a]	72.0 (73.5)	70.5 (70.5)
Peak viscosity (BU)	420 (720)	550 (810)	730 (1600)
Peak temperature (C)	95.0 (95.0)	95.0 (95.0)	82.5 (79.5)
	Sedimentation volume (mL)		
	56.7	17	31.9
	Falling number (sec)		
	635	536	NA

[a] Figures in brackets were measured in the presence of mercuric acetate as enzyme inhibitor.
NA=not applicable.

Table 4. Starch and Amylose Concentration of Waxy and Normal Wheat Grains and their Starch isolate Yield and Extraction Efficiencies (dry basis)

Wheat type	Starch (%)	Amylose (% of starch)	Starch yield (g/100g grain)	Starch efficiency extraction (%)	
				Crude[a]	Pure[b]
Waxy	56.3	3.6	53.8	95.6	83.4
Normal	60.5	27.3	56.1	92.7	82.2

[a] (g crude starch isolate/g starch in grain) x 100
[b] (g starch in isolate/g starch in grain) x 100

Table 5. Starch Damage of Waxy and Normal Wheat and Corn Wholemeals and Starches (%dry basis)

Starch source and type	Wholemeal	Starch Isolate
Wheat		
Waxy	4.24	0.79
Normal	3.97	0.44
Corn		
Waxy	-	1.85
Normal	-	1.78

Table 6. Average Diameter and Percent of type A and type B Granule of Waxy and Normal Wheat and Corn Starches

Starch source and type	Diameter (μm)	Type A (%)	Type B (%)
Wheat			
Waxy	6.6 (5.6)[1]	83.1	16.9
Normal	6.9 (6.0)	80.6	19.4
Corn			
Waxy	10.9 (3.5)	-	-
Normal	11.4 (3.4)	-	-

[1] Values in parenthesis indicate standard deviation (STD).

Table 7. Chemical Composition of Waxy and Normal wheat and Corn Starches (dry basis)

Starch source and type	Starch (%)	Amylose (% of starch)	Protein (%)	Fat (%)	Ash (%)
Wheat					
Waxy	92.4	3.2	0.33	0.08	0.04
Normal	94.3	26.9	0.29	0.09	0.11
Corn					
Waxy	92.3	2.9	0.34	0.01	0.07
Normal	94.8	21.0	0.32	0.01	0.08

Table 8. Degree of Crystallinity and Percent Relative Crystallinity of Major Peaks in the X-ray Diffraction Patterns of Waxy and Normal Wheat Starches

Starch type	Crystallinity (%)		X-ray diffraction angle (2θ)			
	Uncorrected	Corrected	15.2 (5.8)[a]	17.2 (5.2)	18.0 (4.9)	23.2 (3.8)
Waxy	16.8	21.2	11.1	15.6	13.3	33.3
Normal	11.5	15.7	6.7	11.1	8.9	24.4

a Numbers in parentheses are starch crystal d-spacing (Å).

Table 9. *In Vitro* Digestibility rates of Waxy and Normal Wheat and Corn Starches

Starch source and type	Digestibility rate (calculated as the slope of first order equation) (mg released maltose/g starch/hr)
Wheat	
Waxy	121.7
Normal	92.7
Corn	
Waxy	126.8
Normal	100.6

Table 10. Pasting Properties of Normal and Waxy Corn and Wheat Starches

Starch source and type	Pasting temperature (°C)	Peak viscosity (BU)	Viscosity at 95°C (BU)	Viscosity after 30 min at 95°C (BU)	Viscosity at 50°C (BU)	Set-back on cooling (BU)	Viscosity after 30 min at 50°C (BU)
Normal							
Corn	75	500	460	390	860	470	800
Wheat	87	200	170	180	490	310	440
Waxy							
Corn	69	1200	530	365	475	110	450
Wheat	62	1090	370	300	350	50	420

Table 11. Free Water of Freshly Cooked Pastes and Syneresis of Expelled and Absorbed Water from Normal and Waxy Corn and Wheat Starch gels after One Week of Cold and Frozen Storage (% gel wt)

Starch source	Free water	Expelled water	Absorbed water	Net syneresis
After 7-days storage at 4°C				
Normal corn	3.47	6.26	12.81	15.6
Normal wheat	2.81	1.07	3.95	2.21
Waxy corn	3.41	0	3.54	0.13
Waxy wheat	4.39	0	4.52	0.14
After 7-days storage at -15°C				
Normal corn	3.47	4.01	57.5	58.04
Normal wheat	2.88	5.48	54.95	57.55
Waxy corn	3.41	0	3.42	0.01
Waxy wheat	4.39	0	4.98	0.59

Table 12. DSC Characteristics of Normal and Waxy Corn and Wheat Starches

Starch source and type	Endothermic transition temperatures (°C)				Enthalpy of gelatinization (ΔH, J/g)
	Onset (To)	Peak (Tp)	Conclusion (Tc)	Range (°C) (Tc - To)	
Normal					
Corn	57.1	70	80.5	23.4	12.7
Wheat	54.6	62.5	73.4	18.8	11.5
Waxy					
Corn	59.8	71.7	83.5	23.7	16.7
Wheat	55.6	66	79.6	24	11.8

Table 13. Chemical composition of flour from waxy, SWS, CWRS and CWES

	moisture (%)	starch (%)	protein (%)	crude fat (%)	Ash (%)
waxy wheat	12.68	71.81	15.63	1.96	0.66
AC Reed	13.57	81.74	11.64	1.01	0.55
Katepwa	15.07	72.13	17.47	1.05	0.53
Glenlea	14.12	76.20	15.30	1.06	0.56
Commercial flour[1]	9.72	79.97	13.68	1.08	0.59

[1] Robin Hood Food Co. All purpose flour.

Table 14. Physicochemical characteristic of flour from waxy wheat, Glenlea, Katepwa and AC Reed

	Waxy wheat	Glenlea	Katepwa	AC Reed
Mixograph				
Peak time (min)	1.6	4.9	3.0	2.0
Peak value (%)	59.5	69.4	66.9	49.3
Slope (%/min)	-7.65	-3.53	-2.87	-6.19
Band width (%)	6.4	33.2	18.9	3.8
Area (%Tq*min)	320.5	388.3	394.3	279.4
Wet gluten (%)				
	37.0	39.15	46.35	33.1
Sedimentation volume (ml)				
	30.8	65.8	46.2	17.8
Swelling power (%)				
	10.83	10.65	10.95	9.99

Table 15. Colors of flour, fresh and cooked dough sheet from waxy wheat, Katepwa and AC Reed

	Hunter color values[1]			
	L	a	b	Y1
		Wheat Flour		
Waxy wheat	85.86	0.56	10.73	23.03
Katepwa	86.93	0.83	10.25	21.93
AC Reed	89.76	0.38	7.79	16.02
Commercial flour[2]	88.21	0.70	7.04	14.91
LSD (p<0.05)	0.504	0.035	0.339	0.631
		Fresh Dough Sheet		
Waxy wheat	78.16	1.34	19.04	44.88
Katepwa	80.25	0.72	20.14	45.35
AC Reed	81.98	-0.17	19.34	41.95
Commercial flour	81.77	0.59	15.76	35.00
LSD (p<0.05)	0.731	0.260	0.599	1.81
		Cooked Dough Sheet[3]		
Waxy wheat	82.55	-1.30	16.77	35.13
Katepwa	84.78	-1.61	14.57	29.24
AC Reed	86.58	-2.17	12.72	24.35
Commercial flour	84.06	-1.57	13.53	27.29
LSD (p<0.05)	0.941	0.149	1.260	3.128

[1] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue); Y1 = yellowness.
[2] Robin Hood Food Co. All Purpose Flour.
[3] Dough sheet was cooked for 6 min in boiling water.

Table 16. Colors of dough sheet from Katepwa and AC Reed flours and blended flours

	Hunter color values[1]			
	L	a	b	Y1
	Fresh Dough Sheet			
Unblended Flour				
Katepwa	80.25	0.72	20.14	45.35
AC Reed	81.98	-0.17	19.34	41.95
Blended Flour[2]				
Katepwa + 5% waxy wheat flour	79.72	0.63	19.38	43.90
Katepwa + 10% waxy wheat flour	79.58	0.99	19.44	44.50
Katepwa + 5% waxy wheat starch	80.93	0.41	19.62	43.53
Katepwa + 10 % waxy wheat starch	81.21	0.38	19.01	42.05
AC Reed + 5% waxy wheat flour	80.33	0.86	19.25	43.65
AC Reed + 10% waxy wheat flour	80.24	0.93	18.83	42.86
AC Reed + 5% waxy wheat starch	82.41	-0.24	18.44	39.75
AC Reed + 10% waxy wheat starch	82.83	-0.32	16.68	35.74
LSD ($p<0.05$)	0.704	0.149	0.841	1.569
	Cooked Dough Sheet[3]			
Unblended flour				
Katepwa	84.78	-1.61	14.57	29.24
AC Reed	86.58	-2.17	12.72	24.35
Blended Flour				
Katepwa + 5% waxy wheat flour	84.65	-1.64	14.89	29.95
Katepwa + 10% waxy wheat flour	84.29	-1.52	14.97	30.34
Katepwa + 5% waxy wheat starch	85.84	-1.77	13.36	26.18
Katepwa + 10% waxy wheat starch	85.88	-1.89	12.55	24.39
AC Reed + 5% waxy wheat flour	84.21	-1.79	15.92	32.20
AC Reed + 10% waxy wheat flour	84.48	-1.71	15.44	31.16
AC Reed + 5% waxy wheat starch	86.93	-2.20	11.93	22.59
AC Reed + 10% waxy wheat starch	87.29	-2.14	10.76	20.17
LSD ($p<0.05$)	0.751	0.116	1.039	2.473

[1] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue); Y1 = yellowness.
[2] Five or ten % portion of common wheat flour was replaced by waxy wheat flour or starch.
[3] Dough sheet was cooked for 6 min in boiling water.

Table 17. Colors of dough sheet of Katepwa (CWRS), Glenlea (CWES) wheat and blended flours

	Hunter color values[1]			
	L	a	b	Yl
Fresh Dough Sheet				
Waxy wheat	79.57	0.95	17.82	40.99
Katepwa	80.15	0.73	18.98	42.86
Glenlea	80.62	1.11	19.17	43.46
LSD (p<0.05)	0.420	0.114	0.421	1.163
Blended Flour[2]				
Katepwa + 5% waxy wheat flour	80.13	0.84	19.05	43.16
Katepwa + 10% waxy wheat flour	80.22	0.76	19.12	43.40
Glenlea + 5% waxy wheat flour	80.30	1.06	19.37	44.02
Glenlea + 10% waxy wheat flour	80.30	1.07	18.94	43.11
Katepwa + 5% waxy wheat starch	81.06	0.48	18.54	41.19
Katepwa + 10% waxy wheat starch	82.11	0.28	17.44	38.18
Glenlea + 5% waxy wheat starch	80.85	0.83	18.79	42.19
Glenlea + 10% waxy wheat starch	81.68	0.66	17.75	39.40
LSD (p<0.05)	0.318	0.124	1.032	0.941
Cooked Dough Sheet[3]				
Waxy wheat	83.80	-1.51	14.87	30.36
Katepwa	85.16	-1.75	13.26	26.17
Glenlea	84.41	-1.57	14.62	29.52
LSD (p<0.05)	1.423	0.321	1.623	4.161
Blended Flour				
Katepwa + 5% waxy wheat flour	85.08	-1.76	13.71	27.15
Katepwa + 10% waxy wheat flour	84.75	-1.70	13.99	27.91
Glenlea + 5% waxy wheat flour	84.15	-1.61	14.87	30.11
Glenlea + 10% waxy wheat flour	84.25	-1.68	14.57	29.36
Katepwa + 5% waxy wheat starch	85.55	-1.87	12.71	24.79
Katepwa + 10% waxy wheat starch	86.40	-1.92	11.30	21.60
Glenlea + 5% waxy wheat starch	84.54	-1.81	14.02	28.00
Glenlea + 10% waxy wheat starch	85.05	-1.82	13.23	26.14
LSD (p<0.05)	0.457	0.151	0.567	1.405

[1] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue); Yl = yellowness.
[2] Five or ten percent portion of common wheat flour was replaced by waxy wheat flour or starch.
[3] Dough sheet was cooked for 6 min in boiling water.

Table 18. Colors of alkaline dough sheets form Katepwa, AC Reed and blended flours

	Hunter color values[1]			
	L	a	b	Y1
	Fresh Dough Sheet			
Unblended Flour				
Katepwa	75.33	-0.40	23.63	55.33
AC Reed	81.22	-1.90	23.23	49.05
Blended Flour[2]				
Katepwa + 5% waxy wheat flour	74.16	-0.18	23.87	56.98
Katepwa + 10% waxy wheat flour	74.17	-0.13	24.05	57.48
Katepwa + 5% waxy wheat starch	76.10	-0.67	23.10	53.21
Katepwa + 10% waxy wheat starch	77.73	-0.89	22.16	49.82
AC Reed + 5% waxy wheat flour	80.13	-1.92	23.95	51.26
AC Reed + 10% waxy wheat flour	79.10	-1.61	24.93	54.38
AC Reed + 5% waxy wheat starch	80.99	-2.11	24.06	50.72
AC Reed + 10% waxy wheat starch	82.31	-2.11	22.12	45.80
LSD (p<0.05)	0.477	0.201	0.791	1.914
	Cooked Dough Sheet[3]			
Unblended Flour				
Katepwa	79.63	-4.87	22.18	44.70
AC Reed	85.36	-5.25	18.10	32.80
Blended Flour				
Katepwa + 5% waxy wheat flour	78.55	-4.42	22.58	46.66
Katepwa + 10% waxy wheat flour	79.50	-4.65	21.95	44.46
Katepwa + 5% waxy wheat starch	80.11	-4.73	21.43	42.86
Katepwa + 10% waxy wheat starch	81.80	-5.00	19.57	37.67
AC Reed + 5% waxy wheat flour	85.11	-5.16	18.59	33.99
AC Reed + 10% waxy wheat flour	83.75	-5.30	20.81	39.15
AC Reed + 5% waxy wheat starch	86.08	-4.78	15.56	27.69
AC Reed + 10% waxy wheat starch	84.78	-5.27	18.91	34.70
LSD (p<0.05)	0.497	0.094	0.937	0.516

[1] L = 100 (white) to 0 (black); a = + (red), - (green); b = +(yellow),- (blue); Y1 = yellowness.
[2] Five or ten percent portion of common wheat flour was replaced by waxy wheat flour or starch.
[3] Dough sheet was cooked for 6 min in boiling water.

Table 19. Texture profile analysis of cooked dough sheet from waxy wheat, Katepwa, AC Reed and blended flour

Flour	HD[1]	CO[1]	AD[1]	SP[1]	GU[1]	CH[1]
Waxy wheat	38.67	0.68	0.24	0.04	26.06	1.26
Katepwa	82.35	0.84	0.53	0.04	70.55	3.42
AC Reed	60.62	0.93	0.59	0.04	56.37	2.73
LSD ($p<0.05$)	7.092	0.191	0.088	-	7.341	0.356
Blended flour						
Katepwa + 5% waxy wheat flour	77.35	0.89	0.62	0.04	68.99	3.38
Katepwa + 10% waxy wheat flour	71.92	1.05	0.55	0.04	75.70	3.46
Katepwa + 5% waxy wheat starch	56.71	0.91	0.52	0.04	51.43	2.31
Katepwa + 10% waxy wheat starch	89.24	0.58	0.74	0.05	51.87	2.87
AC Reed + 5% waxy wheat flour	53.85	0.95	0.47	0.04	51.22	2.48
AC Reed + 10% waxy wheat flour	54.71	0.98	0.50	0.04	53.87	2.61
AC Reed + 5% waxy wheat starch	54.97	1.08	0.71	0.04	59.36	2.87
AC Reed + 10% waxy wheat starch	61.06	1.03	0.59	0.03	62.92	2.65
LSD ($p<0.05$)	10.642	0.139	0.148	0.009	13.619	1.057
Commercial - all purpose[2]	82.35	0.76	0.41	0.04	62.10	3.21

[1] HD, hardness (N); CO, cohesiveness; AD, adhesiveness (N-cm); SP, springiness (cm); GU, gumminess (N); CH, chewiness (N-cm), N=3.

[2] Robin Hood Food Co.

Table 20. Texture profile of cooked dough sheet from waxy wheat, Katepwa, AC Reed, Glenlea and blended flour

Wheat flour	HD[1]	CO[1]	AD[1]	SP[1]	GU[1]	CH[1]	Cooking loss(%)[2]
Waxy wheat	30.39	0.33	0.35	0.03	10.24	0.40	4.67
Katepwa	81.86	0.59	0.66	0.03	49.02	1.90	4.85
AC Reed	67.96	0.60	0.78	0.03	40.93	1.72	6.51
Glenlea	86.20	0.62	0.71	0.05	53.06	3.08	5.94
LSD (p<0.05)	10.979	0.069	0.184	0.005	9.927	0.448	--
blended flour							
Katepwa + 5% waxy wheat flour	65.79	0.54	0.66	0.03	35.48	1.50	4.35
Katepwa + 10% waxy wheat flour	56.67	0.54	0.42	0.04	30.51	1.39	4.37
Katepwa + 5% waxy wheat starch	60.30	0.94	0.49	0.04	56.61	2.47	4.46
Katepwa + 10% waxy wheat starch	57.25	0.94	0.53	0.03	53.81	2.28	4.35
Glenlea + 5% waxy wheat flour	69.48	0.60	0.57	0.04	41.91	2.03	5.98
Glenlea + 10% waxy wheat flour	61.23	0.51	0.51	0.03	31.42	1.33	6.07
Glenlea + 5% waxy wheat starch	55.37	0.57	0.43	0.04	31.49	1.42	5.36
Glenlea + 10% waxy wheat starch	54.06	0.57	0.40	0.03	30.85	1.30	5.29
LSD (p<0.05)	8.535	0.088	0.123	0.009	8.635	0.660	--
Commercial - all purpose[3]	82.35	0.76	0.41	0.04	62.10	3.21	6.02

[1] HD, hardness (N); CO, cohesiveness; AD, adhesiveness (N-cm); SP, springiness (cm); GU, gumminess (N); CH, chewiness (N-cm), N=3.
[2] Cooking loss (%) = weight of dried cooking water (g)/ weight of uncooked noodle (g) x 100.
[3] Robin Hood Food Co.

Table 21. Texture profile of dried noodles prepared from waxy wheat , Katepwa, AC Reed and blended flour

	HD[1]	CO[1]	AD[1]	SP[1]	GU[1]	CH[1]	Cooking loss (%)
Waxy wheat	86.7	0.61	0.07	0.04	52.7	2.30	8.00
Katepwa	215.4	0.70	0.08	0.04	150.3	7.28	4.89
AC Reed	147.5	0.71	0.23	0.04	104.0	4.53	7.45
LSD ($p<0.05$)	14.442	0.081	0.117	0.018	15.293	1.569	--
blended flour							
K + 5% WF[2]	276.2	0.58	0.16	0.04	160.9	7.78	4.97
K + 10 % WF	225.5	0.61	0.19	0.04	138.4	6.69	4.86
K + 5% WS[3]	227.3	0.52	0.21	0.03	127.6	4.94	5.40
K + 10% WS	260.4	0.55	0.23	0.04	141.8	6.86	5.81
LSD ($p<0.05$)	28.849	0.082	0.152	0.00	14.478	0.700	--
AC + 5% WF[4]	201.4	0.59	0.35	0.03	118.8	4.60	7.09
AC + 10% WF	201.1	0.51	0.46	0.04	102.3	4.21	6.98
AC + 5% WS[5]	192.9	0.62	0.20	0.04	118.9	5.17	8.96
AC + 10% WS	167.8	0.61	0.38	0.03	101.7	3.94	7.98
LSD ($p<0.05$)	22.638	0.042	0.372	0.014	9.207	1.134	--
Commercial flour[6] - all purpose	326.0	0.53	0.36	0.05	173.5	9.64	7.49

[1] HD, hardness (N); CO, cohesiveness; AD, adhesiveness (N-cm); SP, springiness (cm); GU, gumminess (N); CH, chewiness (N-cm), N=3.

[2, 3] Five or ten percent portion of Katepwa flour was replaced with waxy wheat flour or starch.

[4, 5] Five or ten percent portion of AC Reed flour was replaced with waxy wheat flour or starch.

[6] Robin Hood Food Co.

Table 22. Eating quality of dried noodle prepared from Katepwa, Glenlea, AC Reed and blended flour with waxy wheat flour or starch[1,2]

Flour	Eating Quality[3]				
	Brightness	Yellowness	Surface smoothness	Softness	Elasticity
Katepwa	5.8b	5.0b	7.0a	6.0a	7.5a
Glenlea	7.0a	6.0a	7.3a	5.8ab	6.5b
AC Reed	7.8a	6.3a	7.0a	5.3b	5.8b
Blended with waxy wheat flour (WF)					
Katepwa + 5%WF	6.8a	6.0a	7.0a	6.3a	7.3a
Katepwa + 10% WF	7.3a	5.8a	7.0a	6.5a	7.3a
Glenlea + 5% WF	7.8a	6.0a	7.5a	6.0a	6.3b
Glenlea + 10% WF	7.0a	6.3a	7.5a	4.8b	6.3b
AC Reed + 5% WF	7.8a	6.3a	7.0a	5.8ab	5.8b
AC Reed + 10% WF	7.8a	6.3a	7.0a	5.8ab	5.8b
Blended with waxy wheat starch (WS)					
Katepwa + 5% WS	7.5a	6.3a	7.3a	6.3a	7.0a
Katepwa + 10% WS	7.8a	6.3a	6.8a	5.3b	6.8ab
Glenlea + 5% WS	7.5a	6.3a	7.3a	5.8ab	6.3b
Glenlea + 10% WS	6.5b	6.0a	7.0a	5.0b	4.8c
AC Reed + 5% WS	7.0a	6.5a	7.0a	5.0b	5.3c
AC Reed + 10% WS	6.5b	6.5a	7.0a	5.0b	5.0c

[1] 9 scale; 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like or dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely.

[2] Dried noodle was cooked for 6 min in boiling water.

[3] Means in a column followed by the same letters are not significantly different.

Table 23. Colors of pasta prepared from semolina blended with waxy wheat flour or starch[1]

Replacement (%) in semolina[2]	Hunter color values[3]			
	L	a	b	Y
Waxy wheat flour				
0 %	81.16	-0.64	25.26	54.95
10 %	82.03	-0.79	24.90	53.45
20 %	81.90	-1.16	23.11	49.32
30 %	80.65	-0.55	23.22	50.88
40 %	80.02	-0.38	21.64	47.65
LSD (p<0.05)	0.509	0.208	0.502	1.359
Waxy wheat starch				
0 %	81.16	-0.64	25.26	54.95
10 %	82.51	-1.41	22.45	47.38
20 %	83.50	-1.46	16.34	33.85
30 %	85.10	-1.78	19.73	40.01
LSD (p<0.05)	0.461	0.384	0.957	2.529

[1] N=4.
[2] Semolina was replaced by waxy wheat flour (0 to 40%) or waxy wheat starch (0 to 30%).
[3] L = 100 (white) to 0 (black); a = + (red), - (green); b = + (yellow), - (blue); Y = yellowness.

Table 24. Eating quality of pasta products processed from semolina and blended with waxy wheat flour or starch[1, 2]

Ingredient	Firmness	Stickiness	Color	Appearance	Flavor
Semolina (100%)	3.8a	3.3a	3.0ab	3.8a	3.3a
Semolina with waxy wheat flour					
10 % waxy wheat flour	3.0b	3.0a	2.5b	3.3a	3.0a
20 % waxy wheat flour	2.5b	2.8a	2.3b	3.0a	2.8a
30 % waxy wheat flour	2.5b	2.3b	2.3b	2.3b	2.5b
40 % waxy wheat flour	2.3b	2.8a	2.8b	2.0b	2.8a
Semolina with waxy wheat starch					
10 % waxy wheat starch	2.3b	2.8a	3.8a	3.0a	2.8a
20 % waxy wheat starch	2.5b	3.0a	2.8b	1.8b	3.3a
30 % waxy wheat starch	2.3b	2.5ab	2.5b	2.0b	3.0a

[1] 4 = good, 3 = fair, 2 = poor, 1 = very poor.
[2] Means in a column followed by the same letters are not significantly different.

Table 25. Eating quality of macaroni products processed from semolina and blended with waxy wheat flour or starch[1, 2]

Ingredient	Firmness	Stickiness	Color	Appearance	Flavor
Semolina (100%)	2.8a	3.0a	3.3ab	2.0b	2.8a
Semolina with waxy wheat flour					
10 % waxy wheat flour	2.5a	3.0a	3.3ab	2.0b	2.8a
20 % waxy wheat flour	2.8a	2.8a	2.8b	2.8a	2.5a
30 % waxy wheat flour	2.5c	2.5a	3.0b	2.5b	2.3b
40 % waxy wheat flour	2.5c	2.8a	3.3ab	2.3b	2.8a
Semolina with waxy wheat starch					
10 % waxy wheat starch	3.0a	3.0a	4.0a	3.3a	3.0a
20 % waxy wheat starch	2.8a	2.5a	3.5a	2.5b	2.8a
30 % waxy wheat starch	2.3b	2.5a	3.5a	2.8a	2.8a

[1] 4 = good, 3 = fair, 2 = poor, 1 = very poor.
[2] Means in a column followed by the same letters are not significantly different.

Table 26. Chemical composition of flours blended with waxy wheat meal prior to cookie processing

	Protein (%)	Starch (%)	Ash (%)	TDF (%)
Flour				
waxy wheat	17.6	77.8	0.52	6.08
AC Reed	11.0	83.7	0.48	3.01
CDC Bavaria	16.3	75.3	0.57	3.00
Katepwa	16.4	79.6	0.76	4.01
Glenlea	12.1	82.9	0.69	3.51
Flour blended with waxy wheat meal (5%)				
AC Reed	11.3	84.7	0.59	3.57
CDC Bavaria	16.6	76.6	0.64	3.27
Katepwa	16.4	78.8	0.79	4.12
Glenlea	12.5	81.9	0.75	3.81
Flour blended with waxy wheat meal (80%)				
AC Reed	16.0	65.4	1.51	12.75
CDC Bavaria	17.1	63.7	1.54	12.91
Katepwa	17.1	63.1	1.57	13.10
Glenlea	16.8	64.4	1.56	12.98

Table 27. Chemical composition of flours blended with waxy wheat flour prior to cookie processing

	Protein (%)	Starch (%)	Ash (%)	TDF (%)
Flour				
waxy wheat	17.6	77.8	0.52	6.08
AC Reed	11.0	83.7	0.48	3.01
CDC Bavaria	16.3	75.3	0.57	3.00
Katepwa	16.4	79.6	0.76	4.01
Glenlea	12.1	82.9	0.69	3.51
Flour blended with waxy wheat flour (5%)				
AC Reed	11.3	83.8	0.51	2.51
CDC Bavaria	16.7	78.9	0.58	3.12
Katepwa	16.3	79.9	0.71	3.61
Glenlea	12.6	81.7	0.68	2.37
Flour blended with waxy wheat flour (80%)				
AC Reed	15.3	76.4	0.61	4.14
CDC Bavaria	16.6	74.6	0.62	4.70
Katepwa	16.5	75.1	0.66	4.16
Glenlea	16.1	76.2	0.64	4.05

Table 28. Baking quality of AC Reed flour blends with waxy wheat meal, flour and starch for cookies

	Cookie wt.(g)	Diameter (D, mm)	Thickness (T, mm)	Spread factor (D/T)	Surface color	Interior color
AC Reed flour (100 %)	23.0	8.4	0.9	9.64	brown	yellow
Percent of blending with waxy wheat meal						
20	23.3	8.1	0.9	8.9	brown	yellow
40	23.5	7.9	1.0	8.19	dark brown	brown
80	23.3	7.3	1.0	7.08	dark brown	dark brown
Percent of blending with waxy wheat flour						
20	23.0	8.0	0.9	8.52	brown	yellow
40	23.2	7.6	1.0	7.79	brown	yellow
80	23.7	6.9	1.1	6.51	brown	yellow
Percent of blending with waxy wheat starch						
1	23.0	8.2	0.9	9.48	brown	yellow
3	22.6	8.2	0.9	9.31	brown	light yellow
5	22.8	8.3	0.9	9.34	light brown	light yellow
10	23.2	8.2	0.9	8.89	light brown	light yellow

Table 29. Baking quality of CDC Bavaria flour blends with waxy wheat meal, flour and starch for cookies

	Cookie wt.(g)	Diameter (D, mm)	Thickness (T, mm)	Spread factor (D/T)	Surface color	Interior color
CDC Bavaria flour (100 %)	23.1	8.1	1.0	8.47	brown	yellow
Percent of blending with waxy wheat meal						
20	23.8	7.7	1.0	7.48	brown	yellow
40	23.5	7.6	1.0	7.22	dark brown	brown
80	23.9	7.2	1.1	6.40	dark brown	dark brown
Percent of blending with waxy wheat flour						
20	23.0	7.6	1.0	7.22	brown	yellow
40	23.3	7.3	1.1	6.87	brown	yellow
80	23.8	6.8	1.1	6.26	brown	yellow
Percent of blending with waxy wheat starch						
1	23.0	7.9	1.0	8.14	brown	yellow
3	23.2	7.9	1.0	8.06	brown	yellow
5	23.1	7.9	1.0	7.87	brown	yellow
10	23.1	7.9	1.0	7.77	brown	yellow

Table 30. Baking quality of cookies from AC Reed flour and flour blends with waxy wheat meal, flour and starch

Flour	Cookie wt.(g)	Diameter (mm)	Thickness (mm)	Spread factor (D/T)	Texture (N)
AC Reed[1]	23.08	8.53	0.82	10.44	215.7
Control (commercial flour)[2]	22.92	6.52	1.12	5.83	360.3
AC Reed flour blends with waxy wheat meal					
20%	23.04	8.00	0.88	9.06	252.3
40%	23.59	7.36	0.98	7.49	360.6
80%	24.01	6.36	1.08	5.87	434.0
AC Reed flour blends with waxy wheat flour					
20%	22.99	8.23	0.85	9.67	265.9
40%	23.10	7.85	0.88	8.89	303.9
80%	23.09	6.86	0.97	7.09	469.5
AC Reed flour blends with waxy wheat starch					
1%	22.60	8.54	0.83	10.26	211.6
5%	22.64	8.43	0.84	10.02	197.8
10%	22.95	8.43	0.86	9.83	179.4

[1] Flour from Year 2000 crop.

[2] Robin Hood Food Co. Cake and Pastry Flour.

Table 31. Baking quality of cookies from CDC Bavaria flour and flour blends with waxy wheat meal, flour and starch

Flour	Cookie wt. (g)	Diameter (mm)	Thickness (mm)	Spread factor (D/T)	Texture (N)
CDC Bavaria[1]	22.38	8.47	0.83	10.26	199.7
AC Reed[1]	23.08	8.53	0.82	10.44	215.7
Control (commercial flour)[2]	22.92	6.52	1.12	5.83	360.3
CDC Bavaria flour blends with waxy wheat meal					
20%	23.30	7.88	0.89	8.83	328.1
40%	24.00	6.76	1.10	6.14	393.8
80%	24.03	6.39	1.10	5.81	558.6
CDC Bavaria flour blends with waxy wheat flour					
20%	22.58	7.93	0.92	8.65	274.1
40%	23.43	7.24	1.00	7.24	366.4
80%	23.40	6.77	1.03	6.60	532.7
CDC Bavaria flour blends with waxy wheat starch					
1%	22.45	8.30	0.83	9.96	192.2
5%	22.62	8.30	0.88	9.49	202.4
10%	22.52	8.29	0.88	9.39	179.4

[1] Flour from year 2000 crop.

[2] Robin Hood Food Co. Cake and Pastry Flour.

Table 32. Evaluation of cookies from soft wheat, AC Reed flour blends with waxy wheat meal, flour and starch[1]

Flour	Appearance	Color	Flavor	Taste	Texture
AC Reed	6.8	6.8	6.6	7.0	7.0
Control (commercial flour)[2]	5.8	5.0	6.1	6.3	5.9
AC Reed flour blends with waxy wheat meal					
20%	6.5	6.5	6.1	6.3	5.8
40%	5.7	5.5	5.5	5.0	5.8
80%	4.8	4.9	5.1	4.6	5.5
AC Reed flour blends with waxy wheat flour					
20%	7.5	7.3	6.4	6.8	6.4
40%	6.6	6.7	6.1	6.2	5.8
80%	5.7	5.9	5.4	5.3	6.0
AC Reed flour blends with waxy wheat starch					
1%	7.0	7.2	6.2	6.7	6.9
5%	7.1	7.0	6.3	6.4	7.1
10%	7.0	7.1	6.2	6.4	5.8
LSD (p<0.05)	1.26	1.21	1.13	1.25	1.34

[1] 9 scale; 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like or dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely, N=10.

[2] Robin Hood Food Co. Cake and Pastry Flour.

Table 33. Evaluation of cookies from soft spelt wheat, CDC Bavaria flour blends with waxy wheat meal, flour and starch[1]

Flour	Appearance	Color	Flavor	Taste	Texture
CDC Bavaria	6.9	7.1	6.8	6.8	6.8
AC Reed	7.3	7.2	6.7	6.3	6.5
Control (commercial flour)[2]	5.2	4.7	5.7	5.7	5.6
CDC Bavaria flour blends with waxy wheat meal					
20%	5.5	5.3	5.3	5.6	4.8
40%	4.6	4.2	4.3	4.2	4.8
80%	4.3	3.7	4.1	3.4	4.1
CDC Bavaria flour blends with waxy wheat flour					
20%	6.5	6.5	6.3	6.8	6.0
40%	5.9	6.3	5.8	4.9	5.4
80%	5.7	6.1	4.9	4.4	5.5
CDC Bavaria flour blends with waxy wheat starch					
1%	6.3	6.6	6.3	6.8	6.2
5%	6.5	6.7	6.3	6.8	6.2
10%	7.1	7.2	6.6	6.8	6.7
LSD (p<0.05)	1.05	0.98	0.97	1.19	1.32

[1] 9 scale; 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like or dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely, N=12.

[2] Robin Hood Food Co. Cake and Pastry Flour.

Table 34. Chemical composition of cookie products from AC Reed, CDC Bavaria, and flour blends with waxy wheat meal, flour and starch

Flour	Protein (%)	Starch (%)	Ash (%)	Crude fat (%)	TDF (%)
AC Reed	8.24	56.1	1.48	17.20	2.19
CDC Bavaria	11.53	53.6	1.39	17.00	1.78
Control (commercial flour)	7.57	55.6	1.51	17.73	2.25
AC Reed flour blends					
AC Reed + 20% Waxy wheat meal	8.82	53.0	1.59	17.43	3.69
AC Reed + 20% Waxy wheat flour	8.83	55.0	1.39	17.26	2.46
AC Reed + 1% Waxy wheat starch	8.28	55.4	1.41	17.20	2.17
AC Reed + 5% Waxy wheat starch	8.10	55.7	1.41	17.07	1.90
CDC Bavaria flour blends					
CDC Bavaria + 20% Waxy wheat meal	11.46	50.7	1.47	17.35	3.29
CDC Bavaria + 20% Waxy wheat flour	11.27	52.9	1.41	17.12	2.01
CDC Bavaria + 1% Waxy wheat starch	11.48	52.7	1.33	17.08	1.73
CDC Bavaria + 5% Waxy wheat starch	11.01	53.1	1.30	16.98	1.73

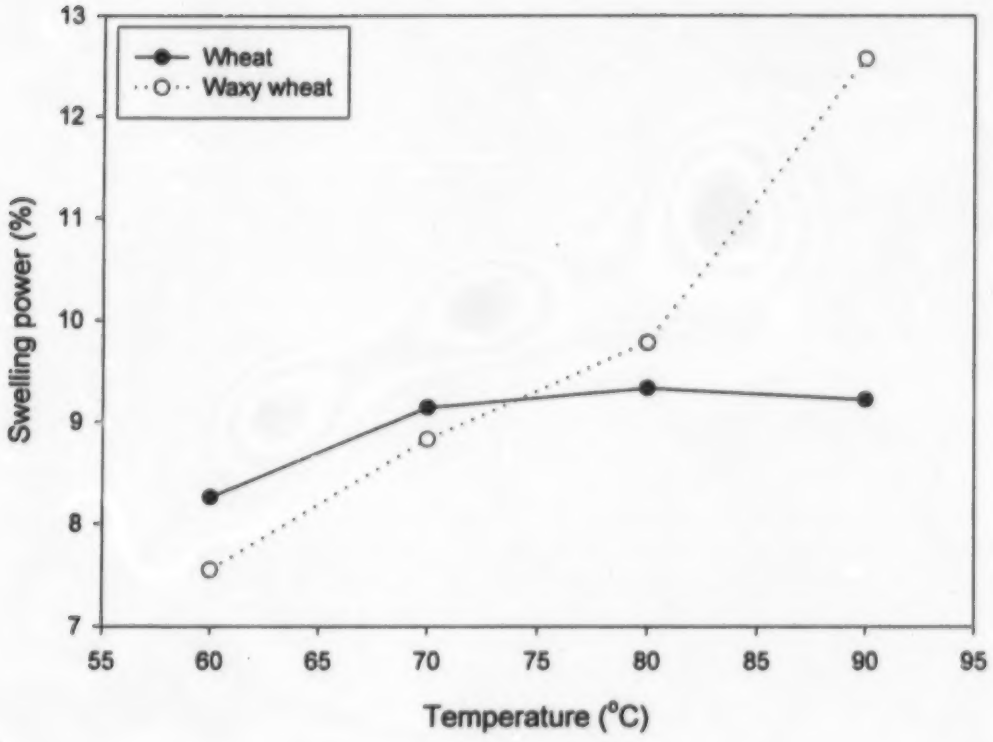


Fig. 1. Swelling power of normal and waxy corn and wheat wholemeals

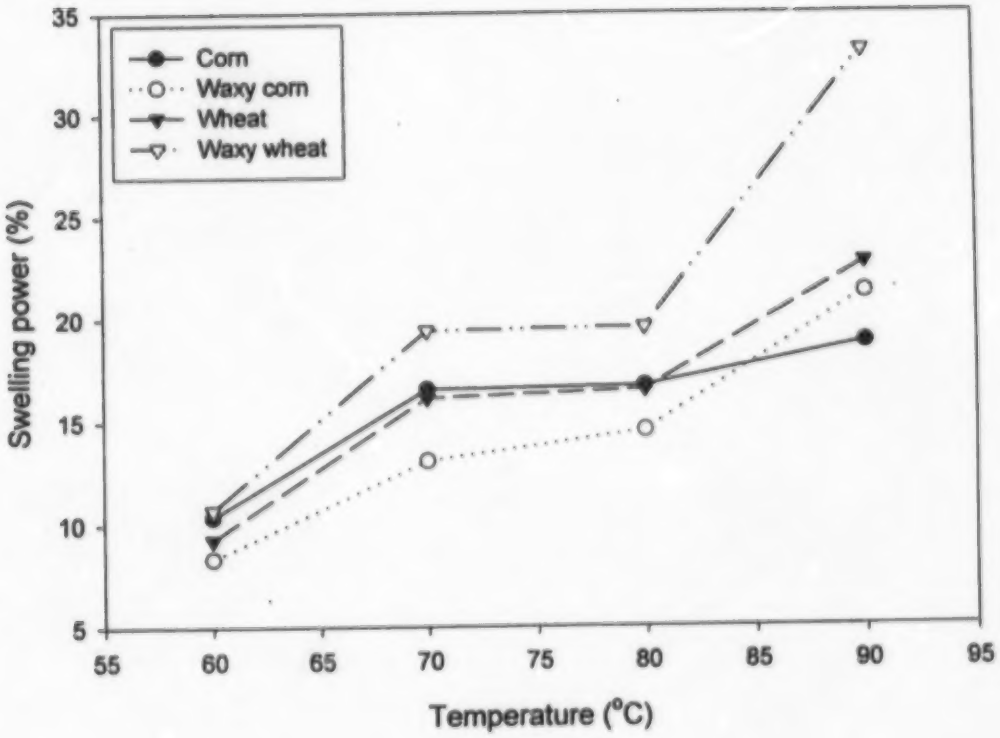


Fig. 2. Swelling power of normal and waxy corn and wheat starches

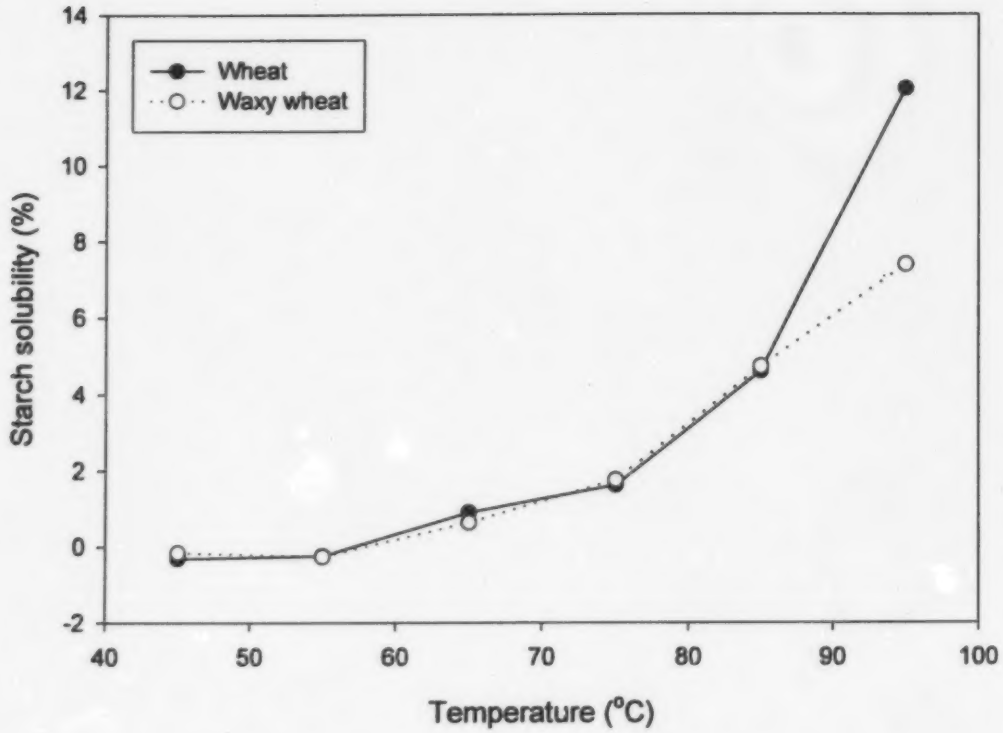


Fig. 3. Starch solubility of normal and waxy wheat grains

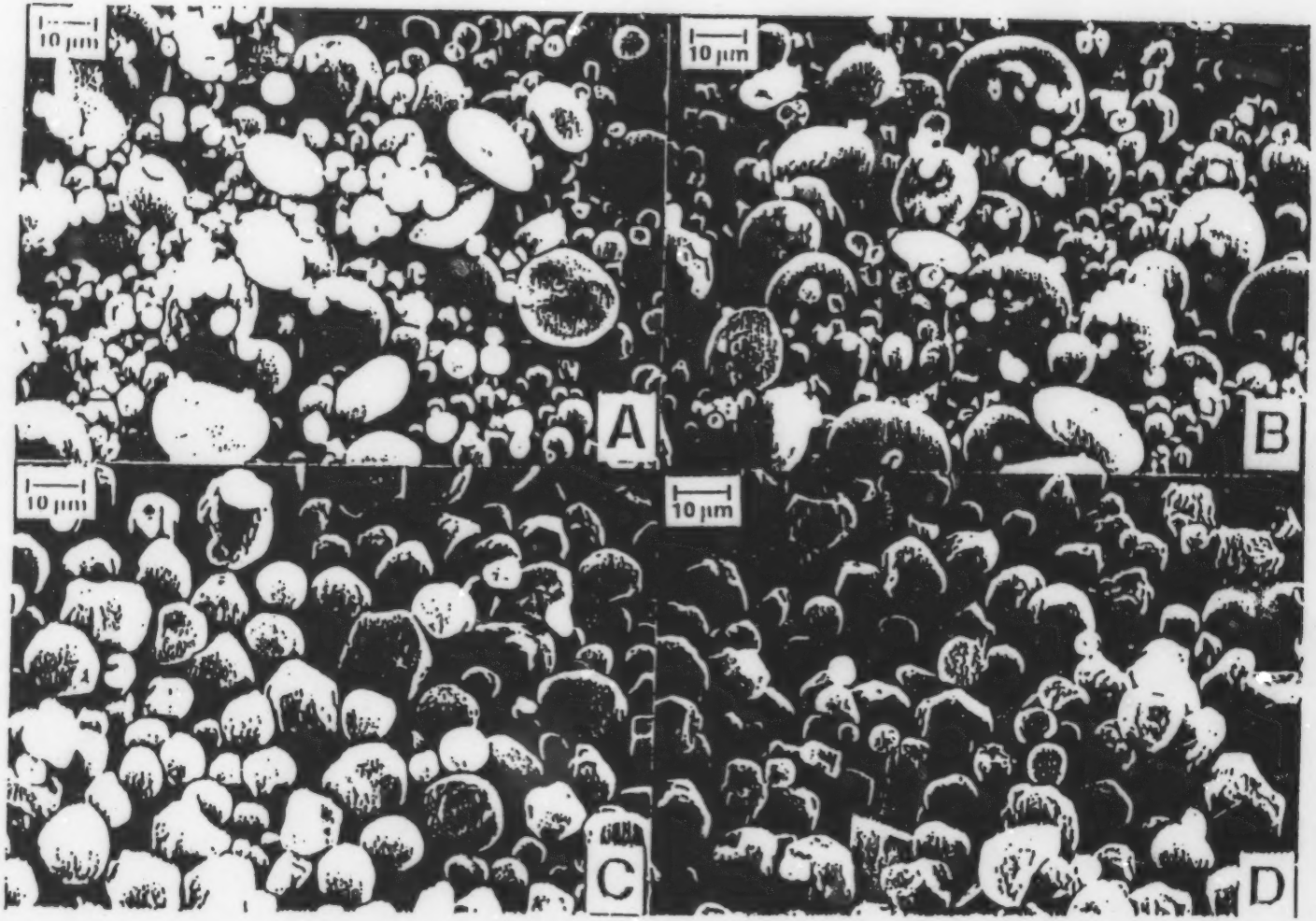


Fig. 4. SEM-photomicrographs of wheat and corn starches: (A) Normal wheat (B) Waxy wheat (C) Normal corn and (D) Waxy corn

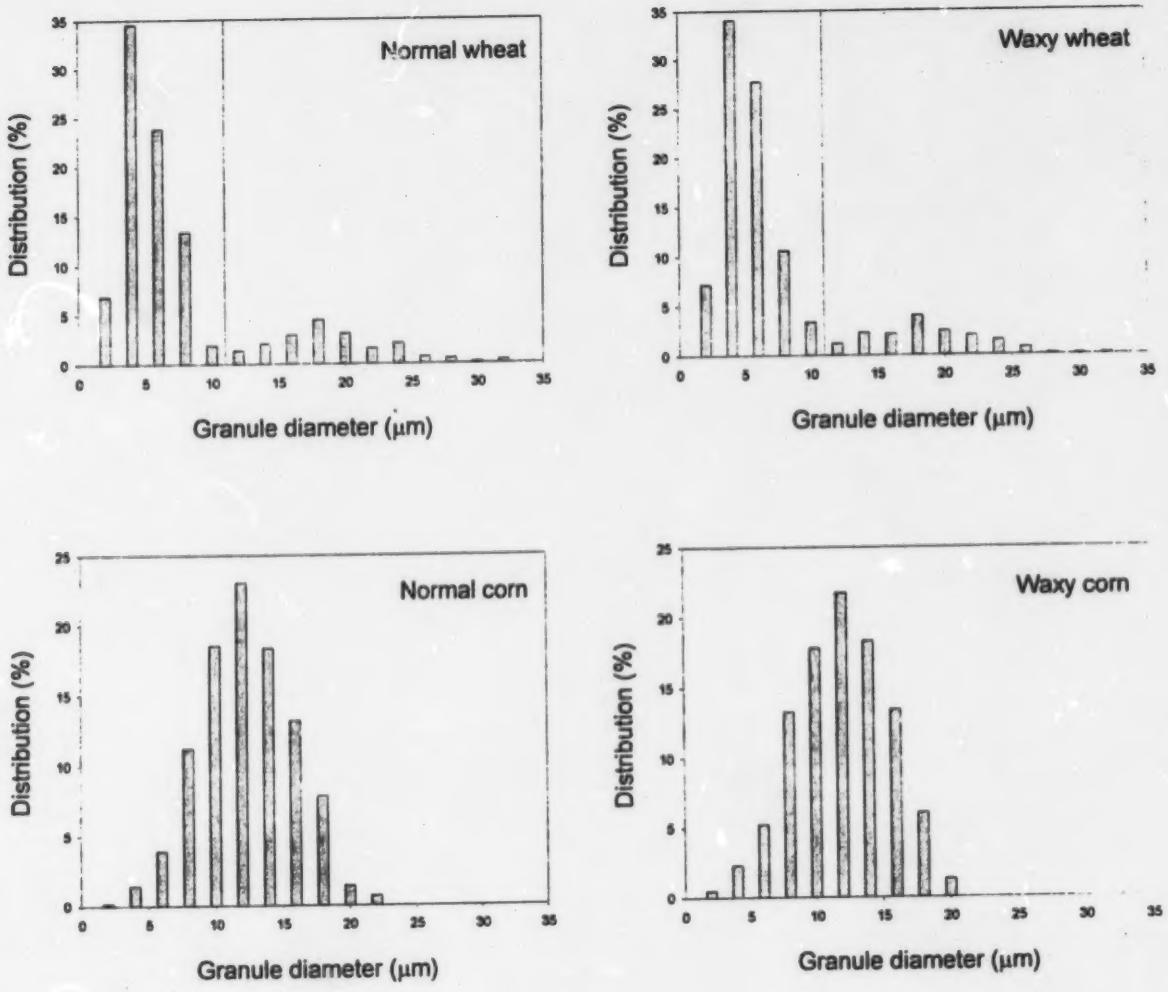


Fig. 5. Granule size distribution of waxy and normal corn and wheat starches

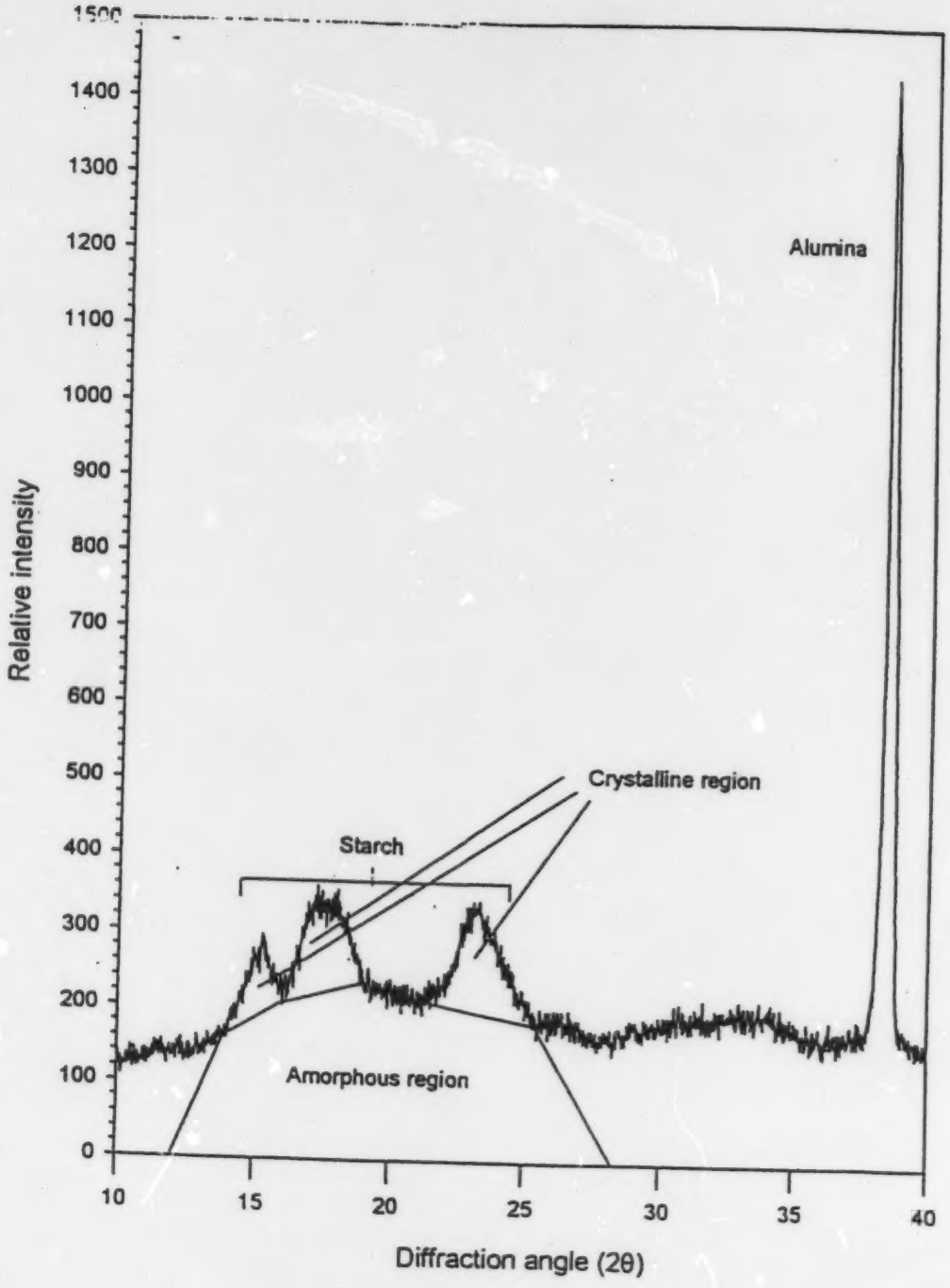


Fig. 6. X-ray diffractogram of waxy wheat starch showing crystilline and amorphous regions

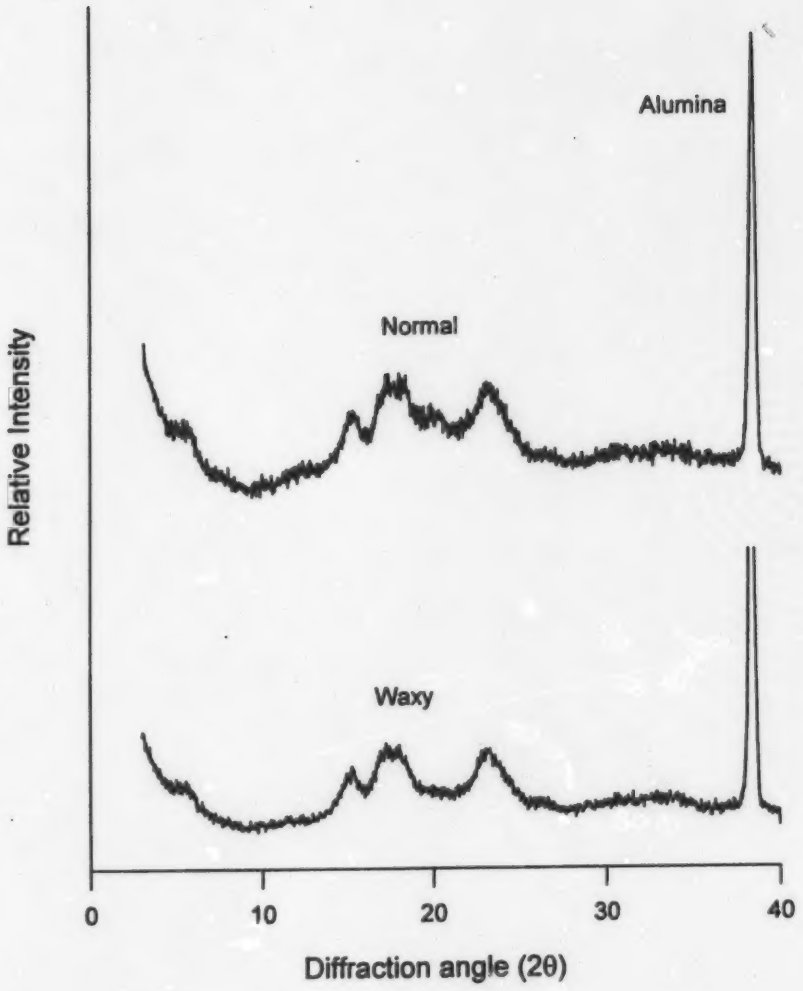


Fig. 7. X-Ray diffractograms of waxy and normal wheat starches

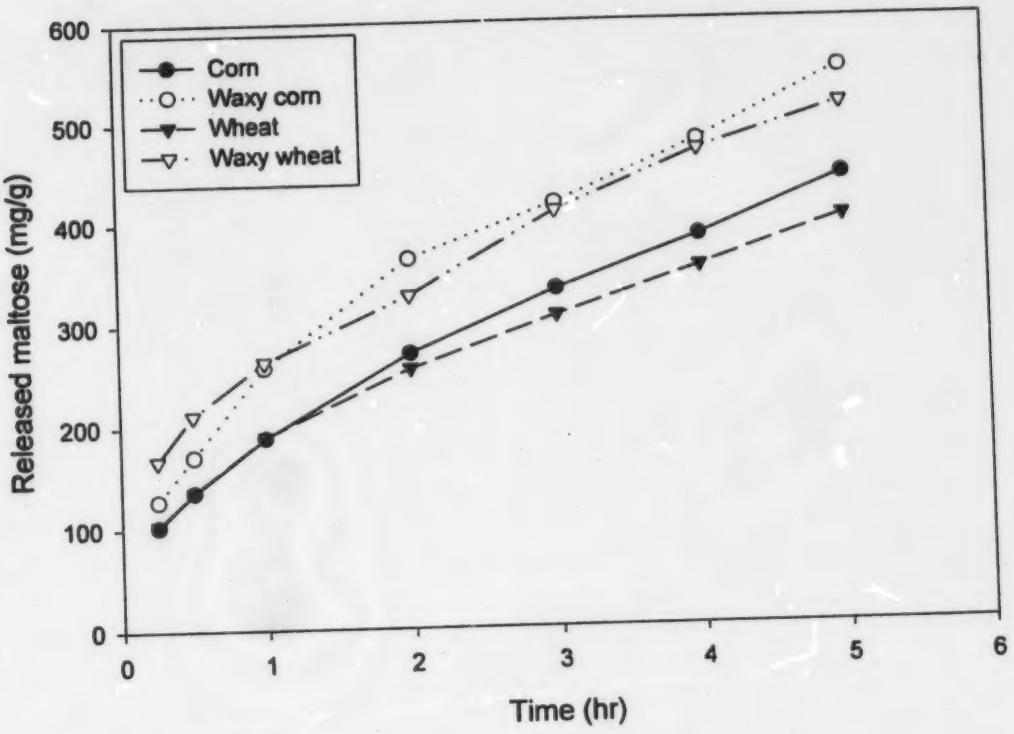


Fig. 8. In vitro digestibility of normal and waxy corn and wheat starches over different incubation times

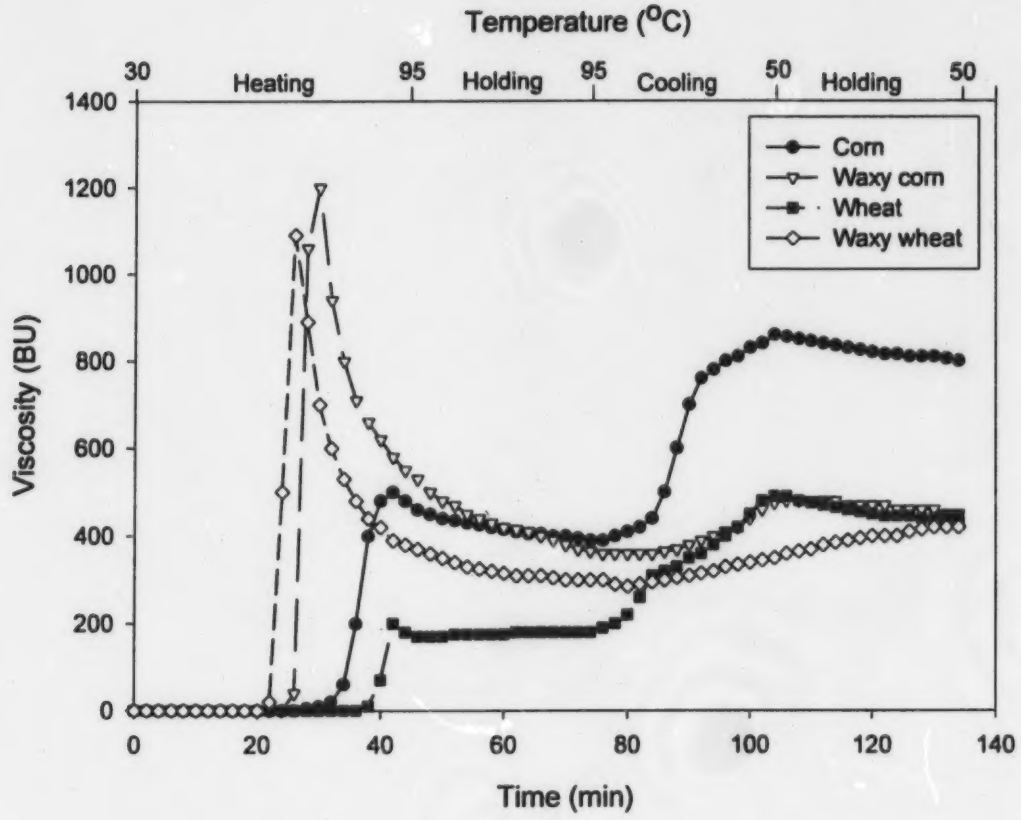


Fig. 9. Visco/amylograph curves of normal and waxy corn and wheat starches

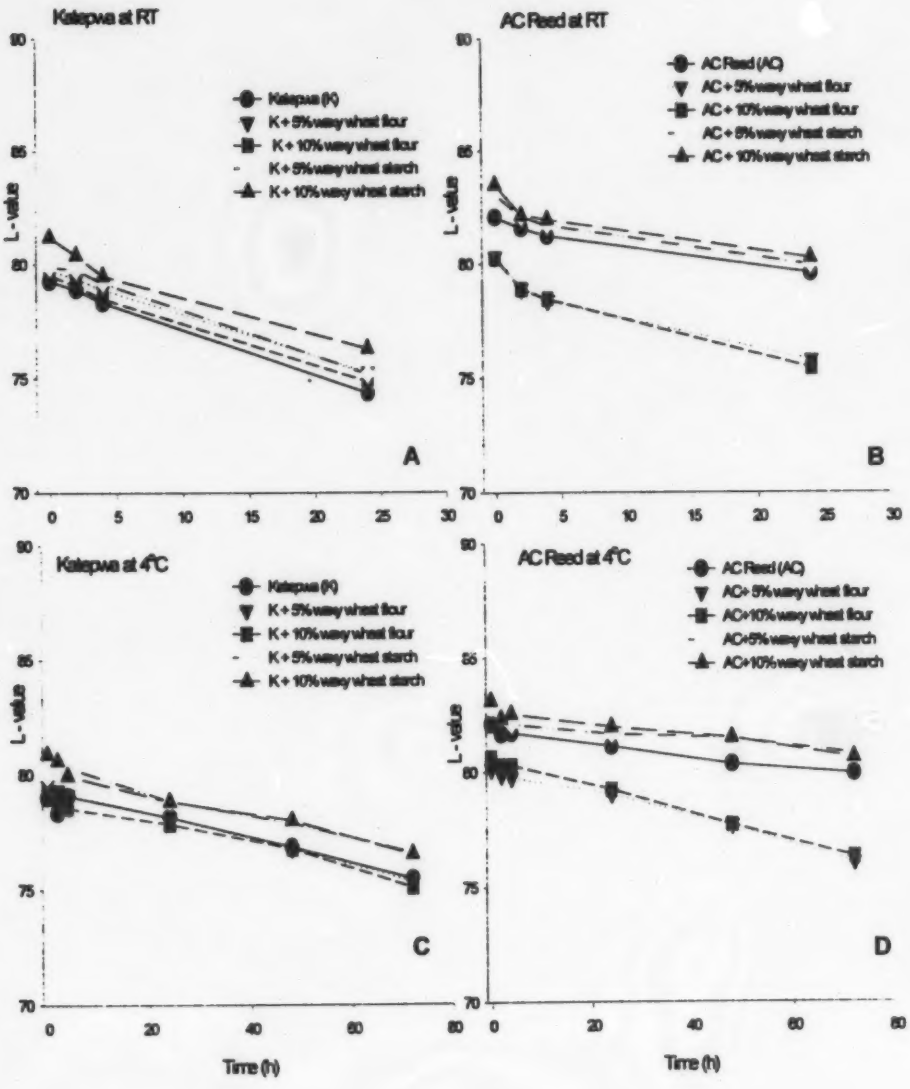


Fig. 10. L-values (Hunter color) of fresh dough prepared from Kalepwa, AC Reed and mixed flour with waxy wheat flour or starch.

A, C, dough prepared from Kalepwa flour (100) and mixed flour with waxy wheat flour of starch (5 or 10 portion of Kalepwa),

B, D, dough prepared from AC Reed flour (100) and mixed flour with waxy wheat flour or starch (5 or 10 portion of AC Reed),

A, B, stored at RT for 24h, C, D, stored at 4C for 72h.

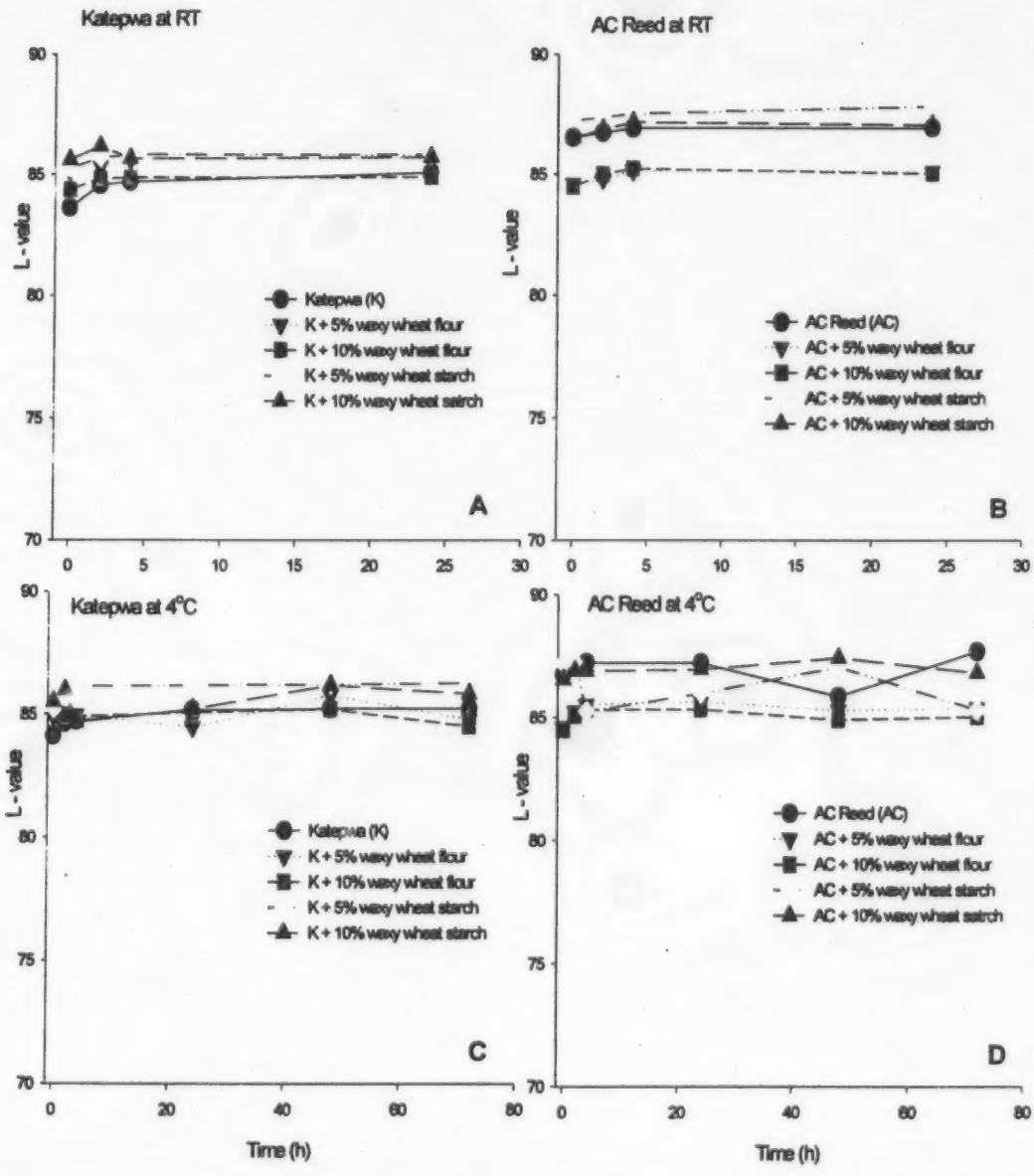


Fig. 11. L - values (Hunter color) of cooked dough prepared from Katepwa, AC Reed and mixed flour with waxy wheat flour or starch.
A; C, dough was prepared from Katepwa flour (100) and mixed flour with waxy wheat flour or starch (5 or 10 portions),
B; D, dough was prepared from AC Reed flour (100) and mixed flour with waxy wheat flour or starch (5 or 10 portions),
A; B, stored at RT for 24h, C; D, stored at 4C for 72h.

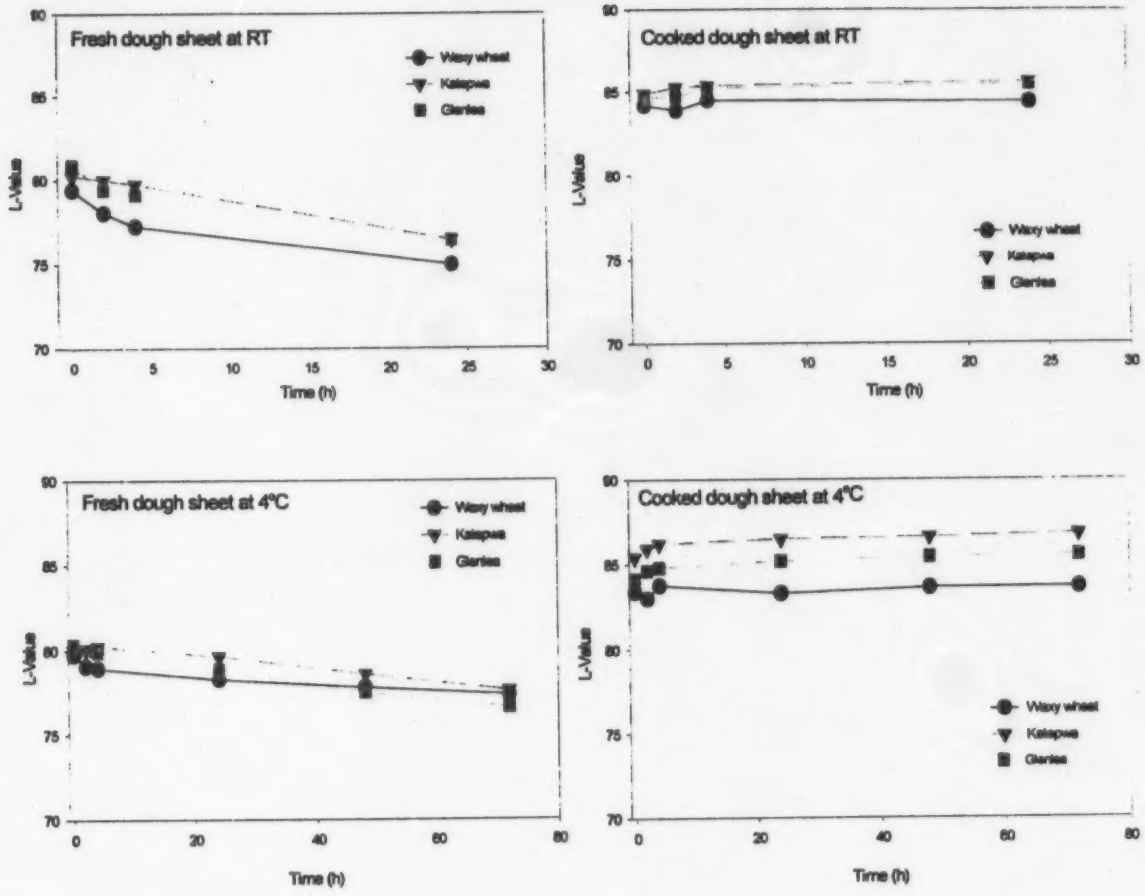


Fig.12. Lightness (L-value, Hunterlab) of fresh and cooked dough sheet from waxy wheat, Katepwa and Glenlea during the storage at room temperature and 4C.

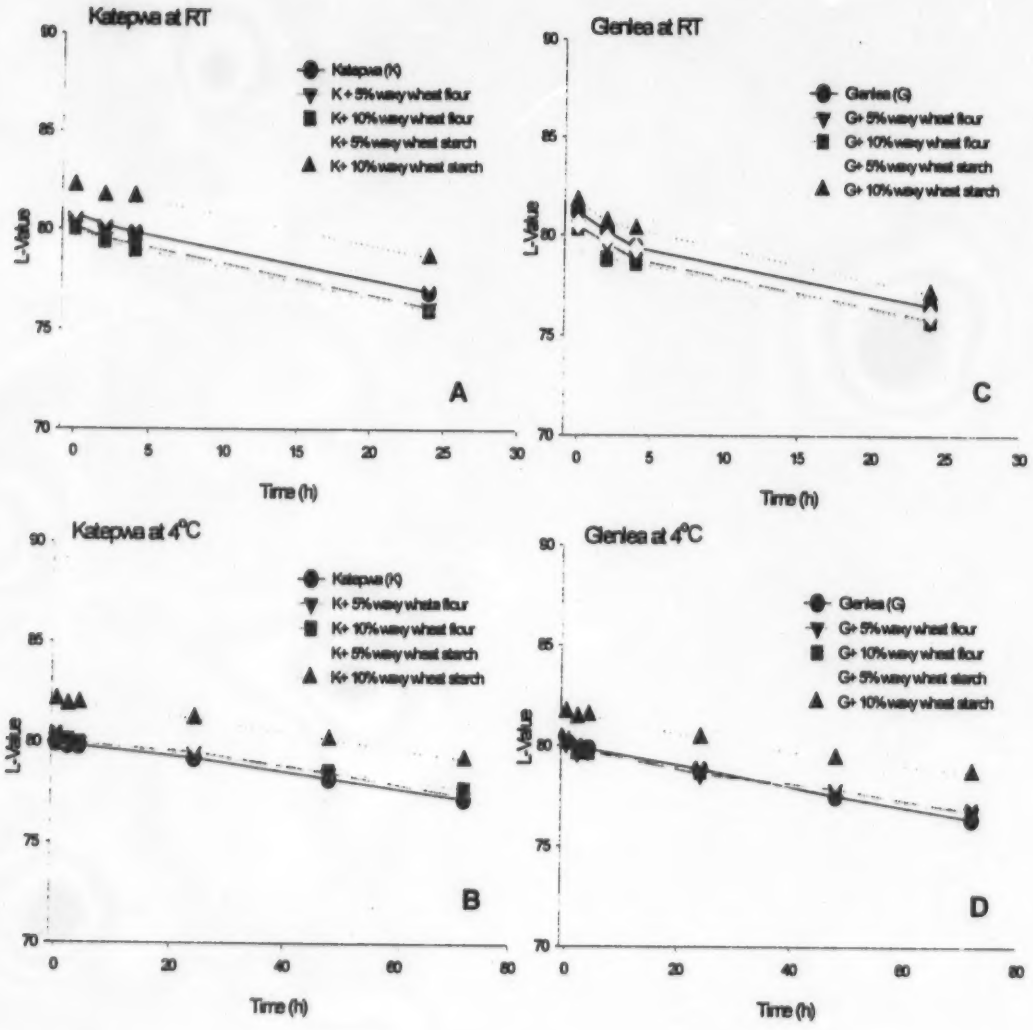


Fig.13. Lightness (L-value, Hunterlab) of fresh dough sheet from Katepwa, Glenlea and blended flour during the storage at room temperature and 4C.
A, B; 5 or 10 portion of Katepwa flour was replaced by waxy wheat flour or starch
C, D; 5 or 10 portion of Glenlea flour was replaced by waxy wheat flour or starch
A, C; stored at RT for 24h, B, D; stored at 4C for 72h.

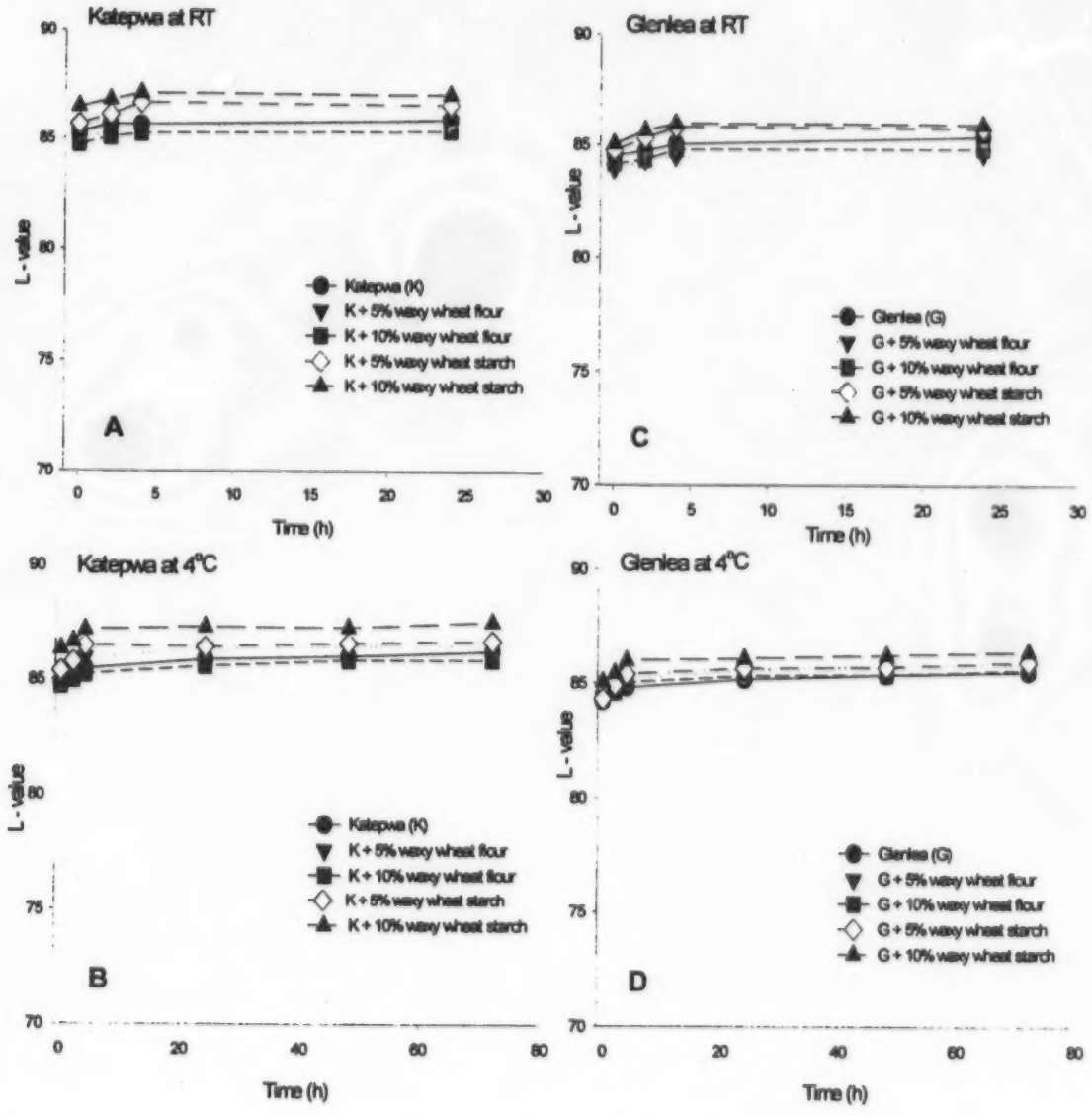


Fig.14. Lightness (L-value, HunterLab) of cooked dough sheet from Katepwa, Glenlea and mixed flour during the storage at room teperature and 4C.
A, B; 5 or 10 portion of Katepwa flour was replaced by waxy wheat flour or starch,
C, D; 5 or 10 portion of Glenlea flour was replaced by waxy wheat flour or starch.
A,C; stored at RT for 24h, B,D; stored at 4C for 72h.

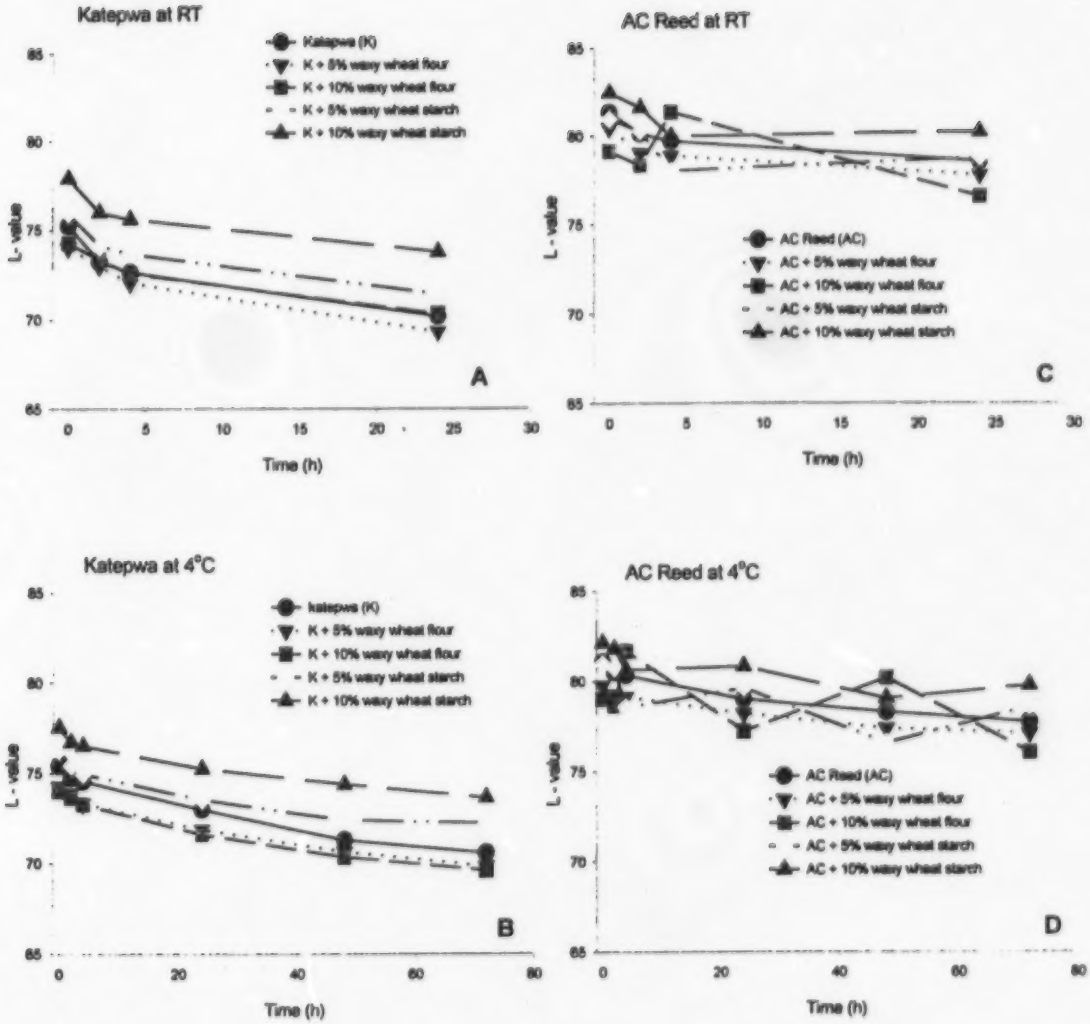


Fig. 15. L-value of fresh alkaline dough sheet from Katepwa, AC Reed and mixed flour with waxy wheat flour or starch during the storage at RT or 4C.
A, B; dough sheet from Katepwa and mixed flour with waxy wheat flour or starch (5 or 10 portion),
C, D; dough sheet from AC Reed and mixed flour with waxy wheat flour or starch (5 or 10 portion),
A, C; stored at RT, B, D; stored at 4C.

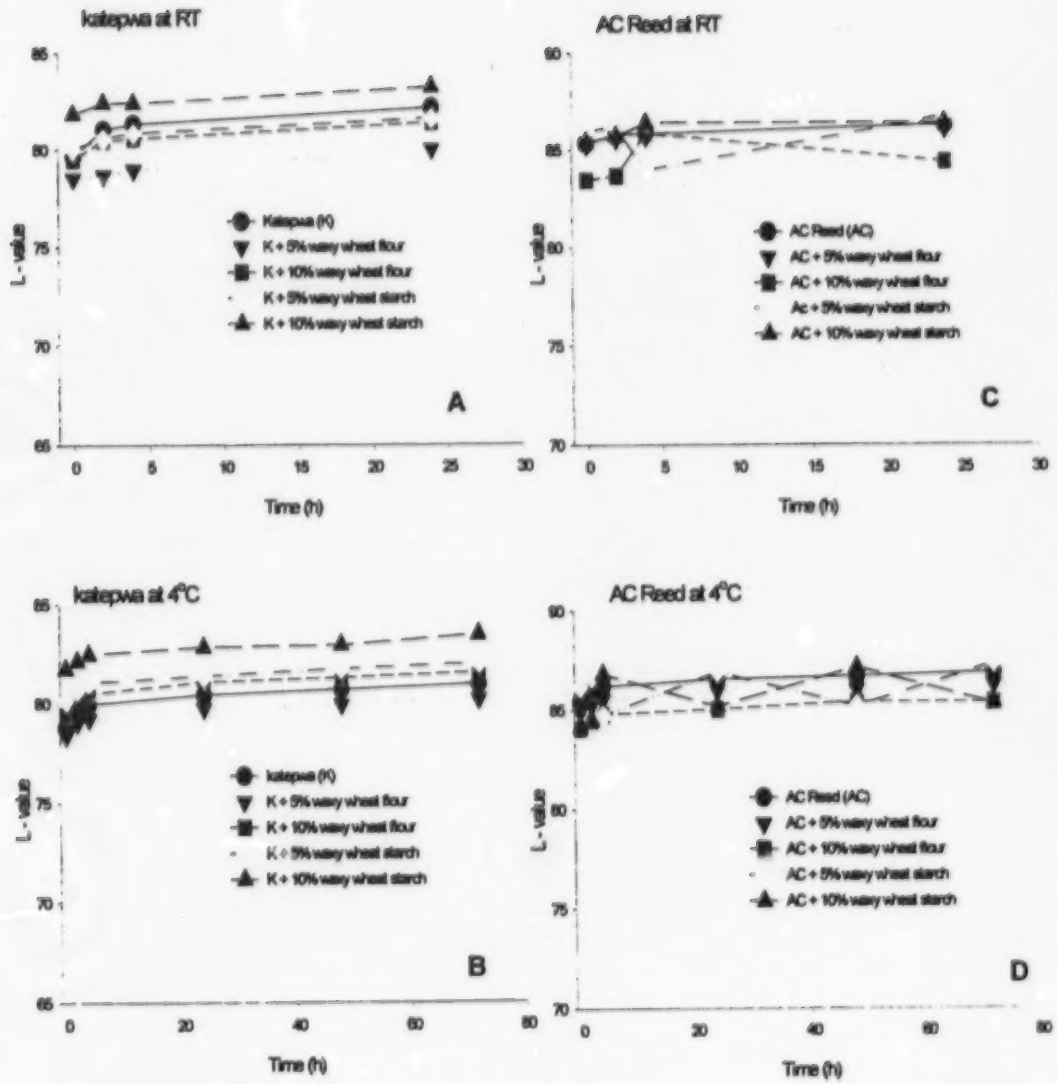


Fig.16. L-value of cooked alkaline dough sheet from Katepwa, AC Reed and mixed flour with waxy wheat flour or starch during the storage at RT or 4C.
A, B; dough from Katepwa and mixed flour with waxy wheat flour or starch (5 or 10 portion),
C, D; dough from AC Reed and mixed flour with waxy wheat flour or starch (5 or 10 portion),
A, C; stored at RT, B, D; stored at 4C.

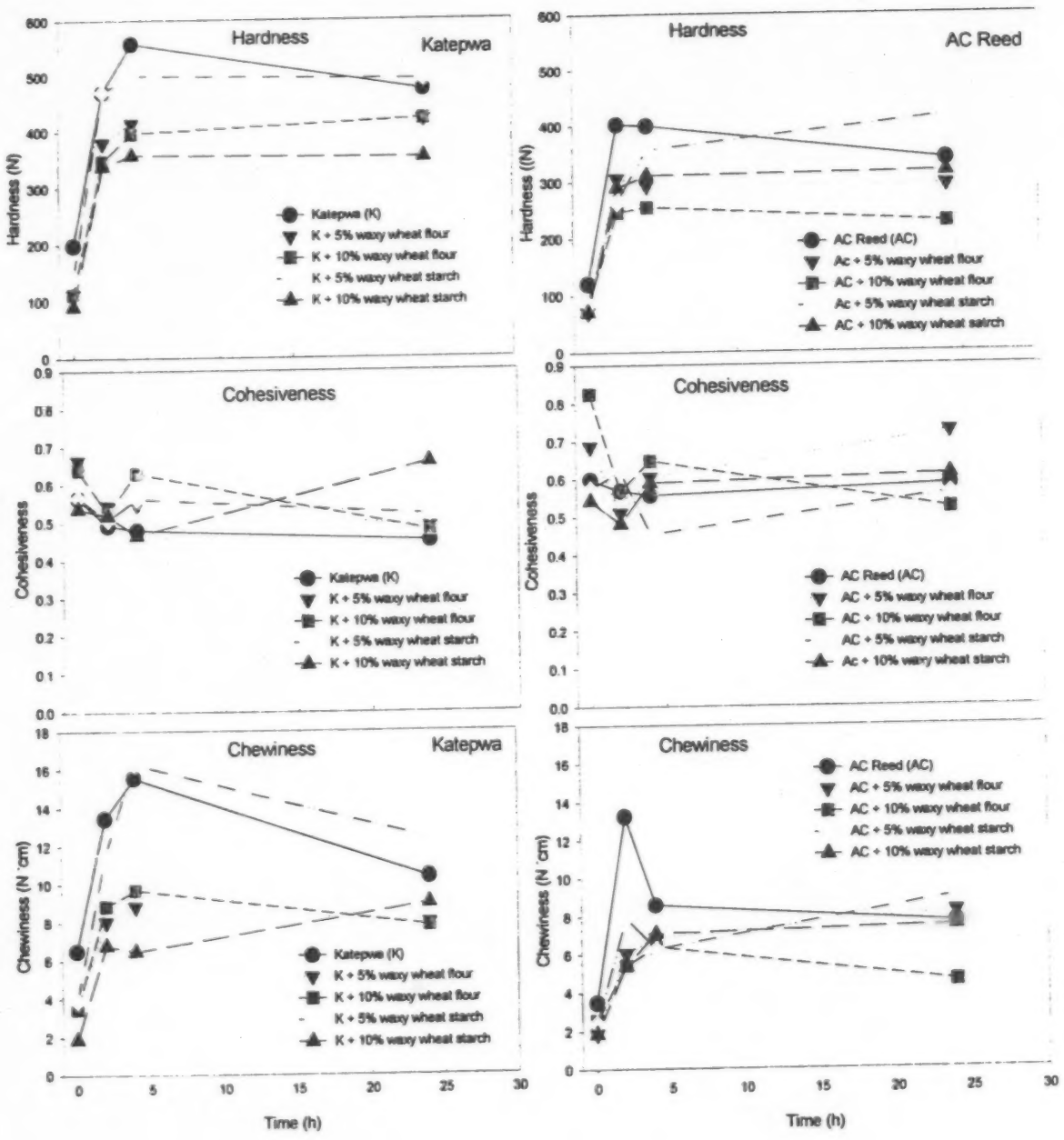


Fig.17. Effect of storage times at 4C on hardness, cohesiveness and chewiness of cooked noodles from Katepwa, AC Reed and mixed flour with waxy wheat flour or starch (5 or 10% replacement).

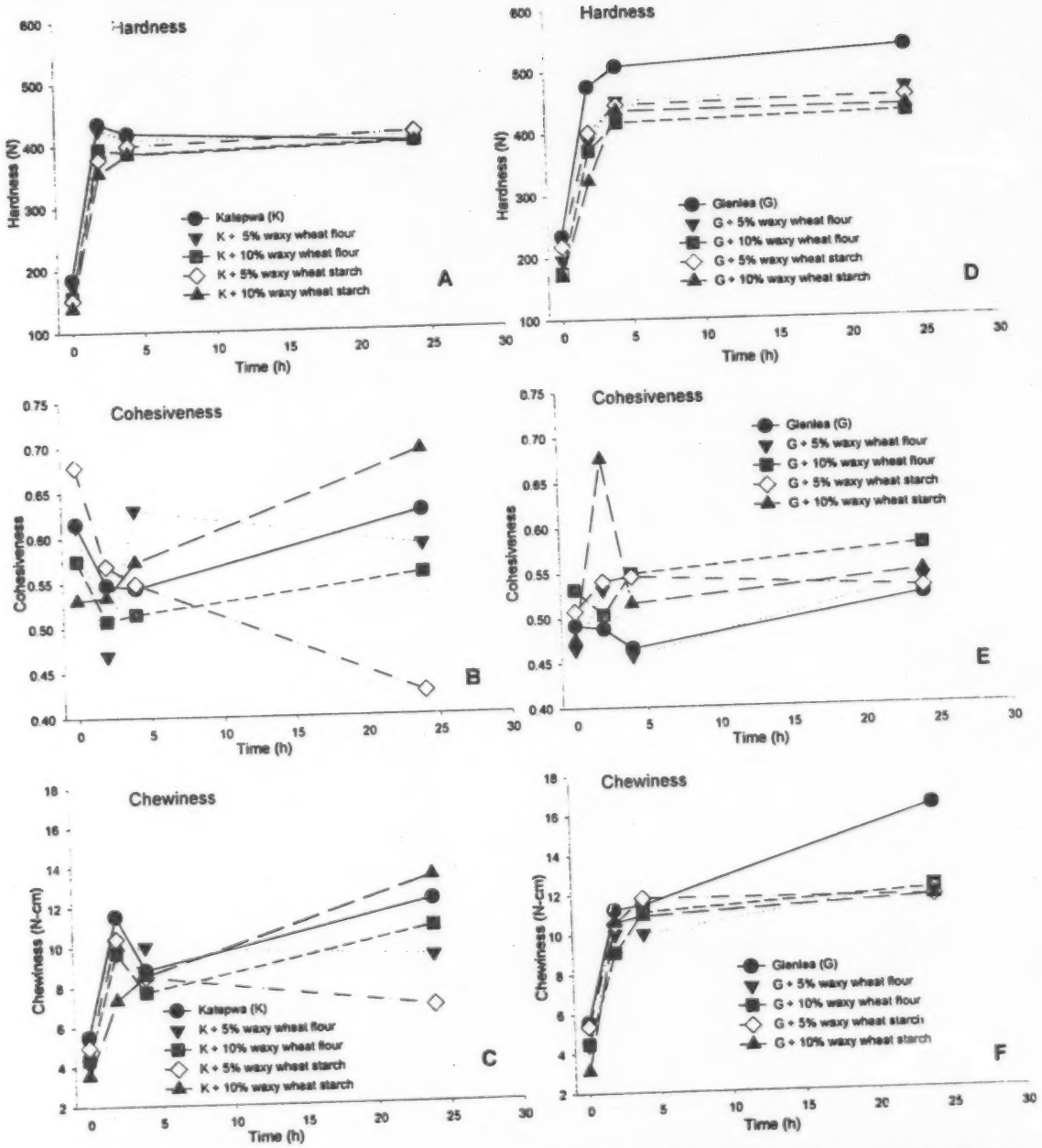


Fig. 18. Effect of storage times at 4C on hardness, cohesiveness and chewiness of cooked noodles from Katepwa, Glenlea and mixed flour with waxy wheat flour or starch (5 or 10% replacement). A, B, C; Katepwa and mixed flour with waxy wheat flour or starch, D, E, F; Glenlea and mixed flour with waxy wheat flour or starch.

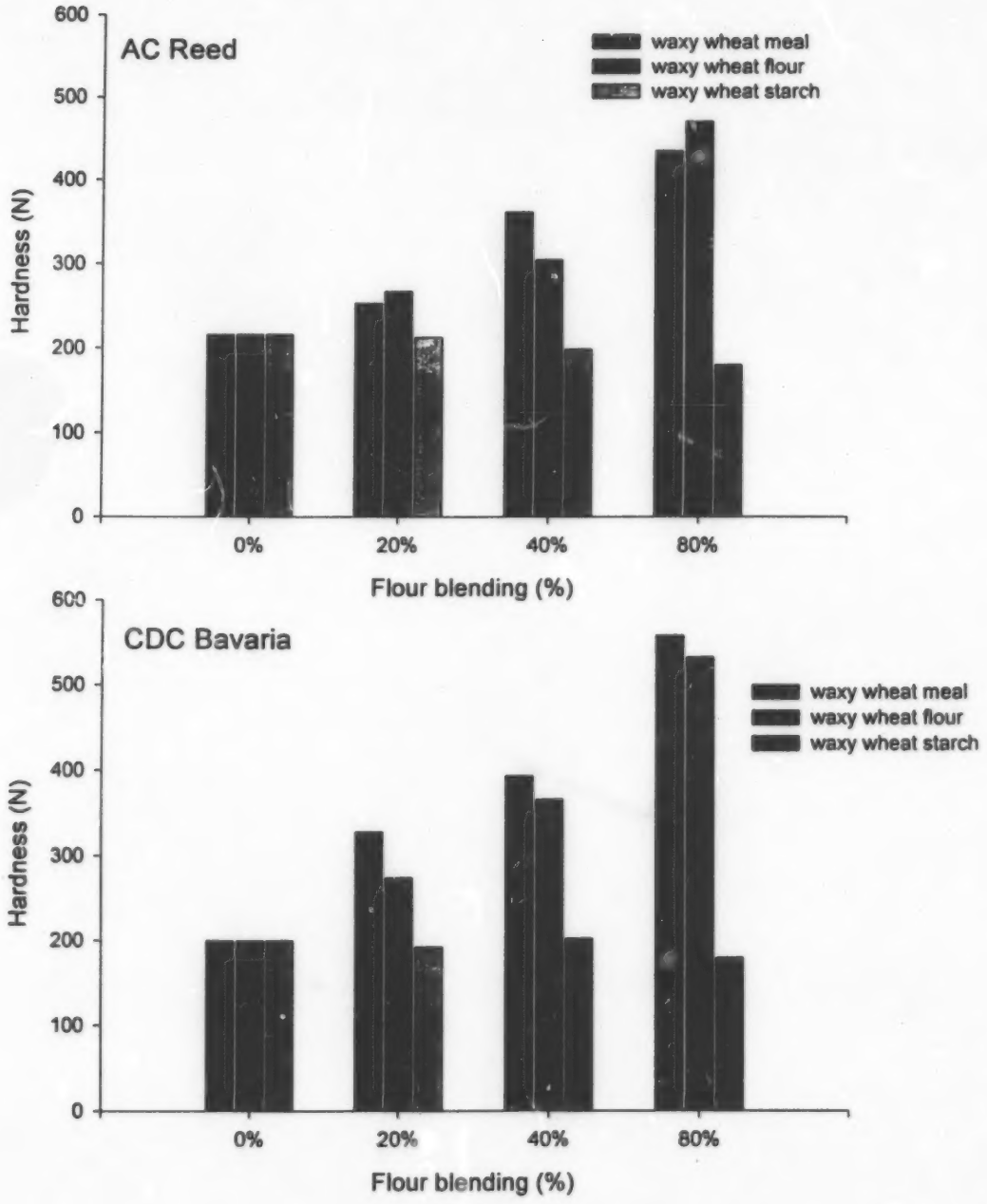


Figure 19. Texture (hardness) of cookies from AC Reed, CDC Bavaria flour and flour blends with waxy wheat meal, flour and starch.

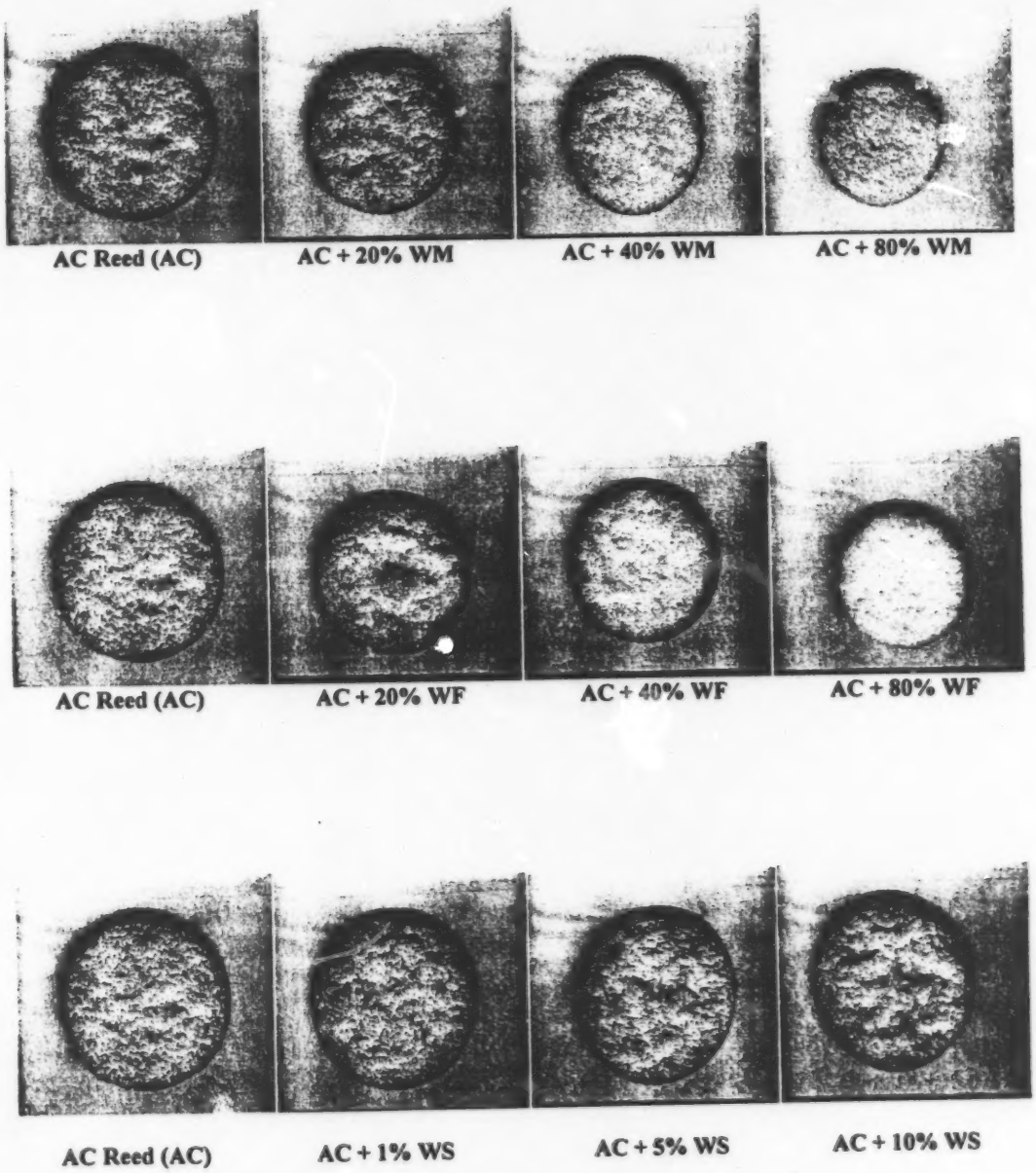
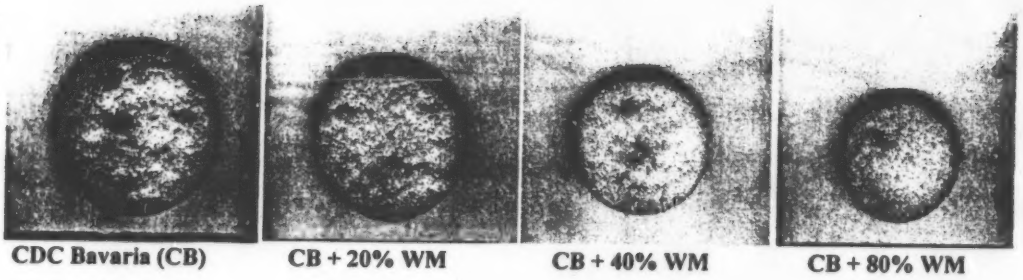
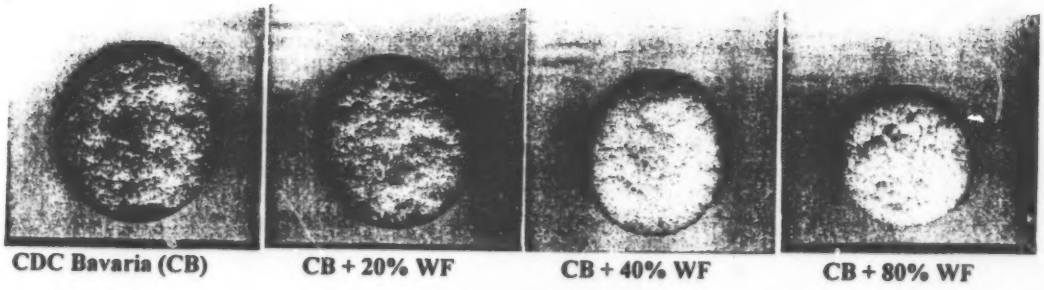


Figure 20. Cookies from AC Reed flour (AC) and flour blends with waxy wheat meal (WM), flour (WF), and starch (WS).





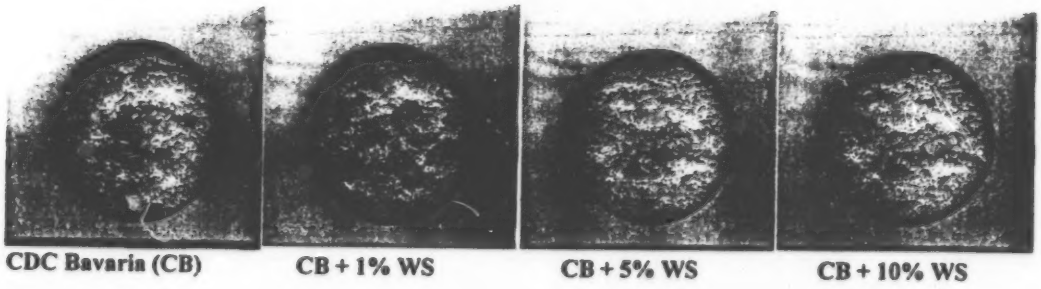


Figure 21. Cookies from CDC Bavaria flour (CB) and flour blends with waxy wheat meal (WM), flour (WF) and starch (WS).